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COMPATIBILITY TEST OF PRESSBOARD WITH TRANSFORMER OIL

SUMMARY

The compatibility of transformer oil with pressboard which is produced according to the IEC 60641-3-1 TYPE B.3.1A and used as insulation in HVAC and HVDC transformers is very important. In order to understand how much the oil is affected from the pressboard and pressboard from the oil, contamination tests should be carried out.

These compatibility tests provide indications about the behaviour of pressboard and oil during the life of the transformer in service. There are several standards for testing of relationship between pressboard and transformer oil, which have been carried out. It was interesting, that some of these tests showed unexpected results. Pressboard obviously absorbed some materials from the oil that normally would have negative effect to criterions like IFT (Interfacial Tension) and DDF (Dielectric Dissipation Factor).

One target of this investigation was to find some of these substances and to describe their behaviour.

Key words: Compatibility, Contamination, Pressboard, Transformer Oil

1. INTRODUCTION

Electrical grids need reliable equipment as transformer, reactor etc. The main part of this equipment is electrical insulation. This consists mainly of paper pressboard and oil. For reliable long time operation a good compatibility of these materials is essential. Therefore some contamination tests have been developed [1],[2] and standardized paper.

Pressboard and oil are aged under defined temperature condition for a certain period and afterwards some criterions are measured [Color, Resistivity, DDF (Dielectric Dissipation Factor), IFT (Interfacial Tension), Acidity][3] and variation limits are given in the following Table I.

In general, a deterioration of the oil is expected [4]. But unexpectedly the combination of pressboard and oil showed a different behaviour. Obviously during these tests some of the oxidation products of the oil have been absorbed by the pressboard and these substances have been identified to have a tenside/detergent behaviour.

To get some more information about this phenomenon, some additional test series have been carried out, including content of furanic compounds in the oil, extraction of surface active materials from the oil and related GC-MS sceening.

Table I - Variation limits

Test / Property	Unit	Manufacturer		ASTM D 3455 [5]	
		Requirement	Variation	Requirement	Variation
		Up to 3 months		Up to 164 h	
Appearance and Sludge (Color)	[---]	[---]	Free of Deposit	[---]	Max.0,5
Dielectric Dissipation Factor	%	[---]	Max.0,5 (90°C)	1,1 (100℃)	[---]
Resistivity at 90℃	Ω.m	[---]	Min.0,2.10^{11}	[---]	[---]
Acidity	mg KOH/g	[---]	Max.0,01	[---]	Max.0,03
Interfacial Tension	mN/m	Min.30	Max.5	Min.38	[---]
Dielectric Strength	kV	[---]	[---]	Min.28	[---]

2. TEST MATERIALS AND EQUIPMENTS

2.1 Test Materials

Transformer oil according to IEC 60296 uninhibited (NYNAS Nytro Taurus)
Pressboard according to IEC 60641-3-1 Type B.3.1A (ENPAYBOARD E3A)

2.2 Test Set and Procedure

Test set up was made according to IEC 60641-2[1]. An oven was used with forced air circulation, controllable 100℃±1℃ as well as glas s bottles each one liter fitted with tight covers. It was important to secure that no oxygen had access to the test, therefore pressboard and oil was treated by vacuum and additionally the oil had been bubbled by nitrogen before the test run.

The pressboard preparation dried in the oven 105℃± 2℃, 16 hours. One bottle was filled only with 750 ml transformer oil “Blank Sample” (oil) (see Photo 1), another bottle was filled with 750 ml transformer oil plus 75 grams pressboard “Board Sample” (oil/board) (see Photo 1). The bottles were placed in an oven with 100℃±1℃ test temperature. Test duration was 3 months with intermediate stops at 4 days, 8 days and 1 month.

Photo 1 – Flasks of Samples

3. MEASUREMENT AND TEST RESULTS

3.1 Criterion of Compatibility Test

The following criterions have been tested and measured on the oil before and after the relevant test duration.

Appearance and Sludge (Color)	ASTM D 1500 (DIN 51578)
Water Content	EN 60814
DDF (Dielectric Dissipation Factor)	IEC 60247
Resistivity	IEC 60247
Relative Permittivity	IEC 60247
Acidity	EN 62021
IFT (Interfacial Tension)	ISO 6295

3.2 Test Results

3.2.1 Water Content [ppm]

Pressboard material absorbs water in transformer oil have been identified.

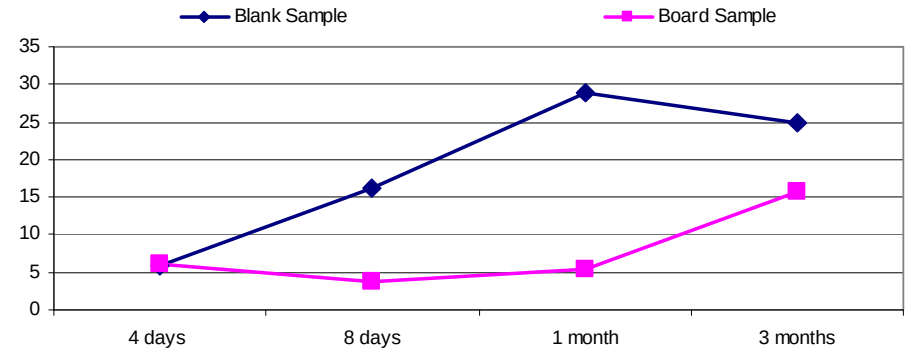


Fig 1 – Water content changing according to the time up to 3 months

3.2.2 Dielectric Dissipation Factor [*10^{-3}]

With this test we can detect even the smallest contamination affecting the electrical properties of transformer oil. According to the tests carried out, even after 3 months test period there has been no contamination in the transformer oil.

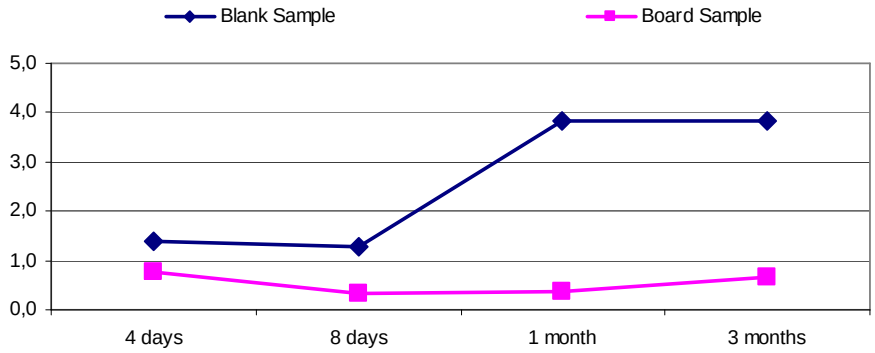


Fig 2 – Dielectric Dissipation Factor changing according to the time up to 3 months

3.2.3 Resistivity [*10^{11} Ωm]

There is a close relation between Dielectric Dissipation Factor test and this test. At the end of 3 months test period, Resistivity values have remained almost the same level as the starting values. This result is proving that pressboard material does not change the properties of the transformer oil.

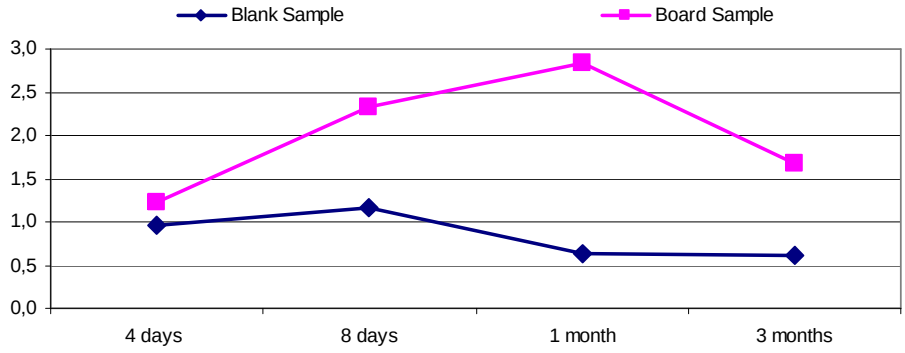


Fig 3 – Resistivity changing according to the time up to 3 months

3.2.4 Relative Permittivity

Relative Permittivity (dielectric constant) is not affected during this test period.

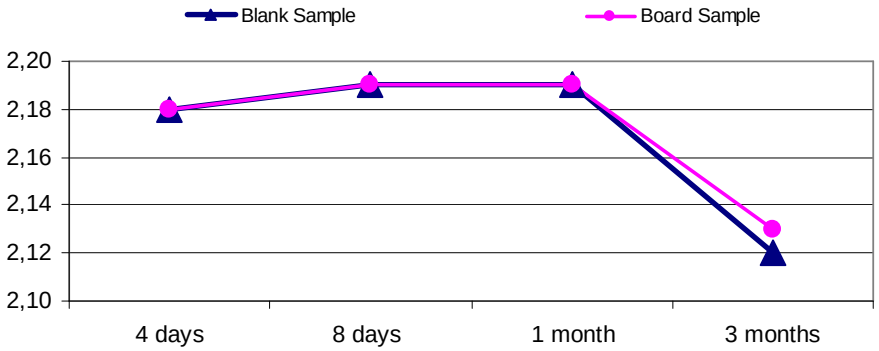


Fig 4 – Relative Permittivity changing according to the time up to 3 months

3.2.5 Acidity [mg KOH/g]

This test is one of the most important tests providing information regarding condition of the oil in service. The effect of the pressboard material to the oil even after 3 months test period is very little resulting in a variation of acidity of less than 0,01 mg KOH/g in comparison to the blank transformer oil sample. This is the variation limit of transformer manufacturer (the relevant variation limit of ASTM D 3455 is 0,03 mg KOH/g after 164 h test period).

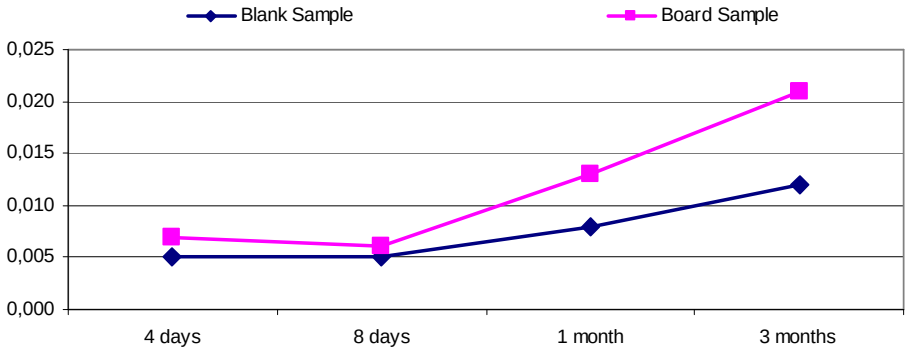


Fig 5 – Acidity changing according to the time up to 3 months

3.2.6 Interfacial Tension [mN/m]

This test is one of the most sensitive tests that provides us with information about the property of transformer oils in service especially regarding a potentially sludge precipitation. It is an additional information together with Acidity (Neutralization Number), Dielectric Dissipation Factor (Tangent Delta, Power Factor) and Water Content tests.

This test showed a perfect compatibility of pressboard material together with transformer oil. IFT (Interfacial Tension) values of samples with pressboard material showed even higher IFT (Interfacial Tension) values than blank transformer oil in this test. This proves once again that pressboard material has no deforming effect on transformer oil.

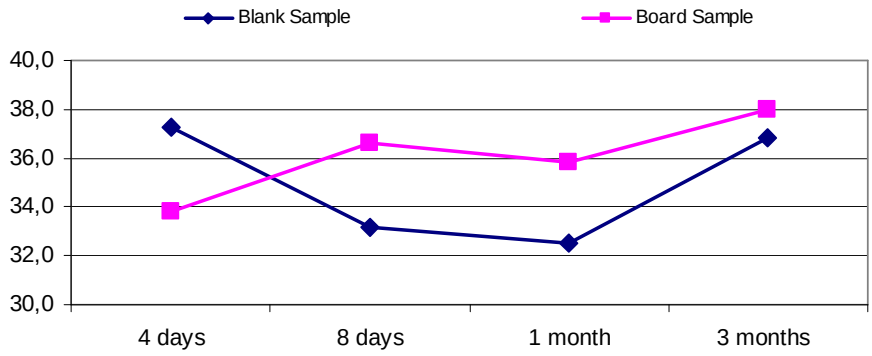


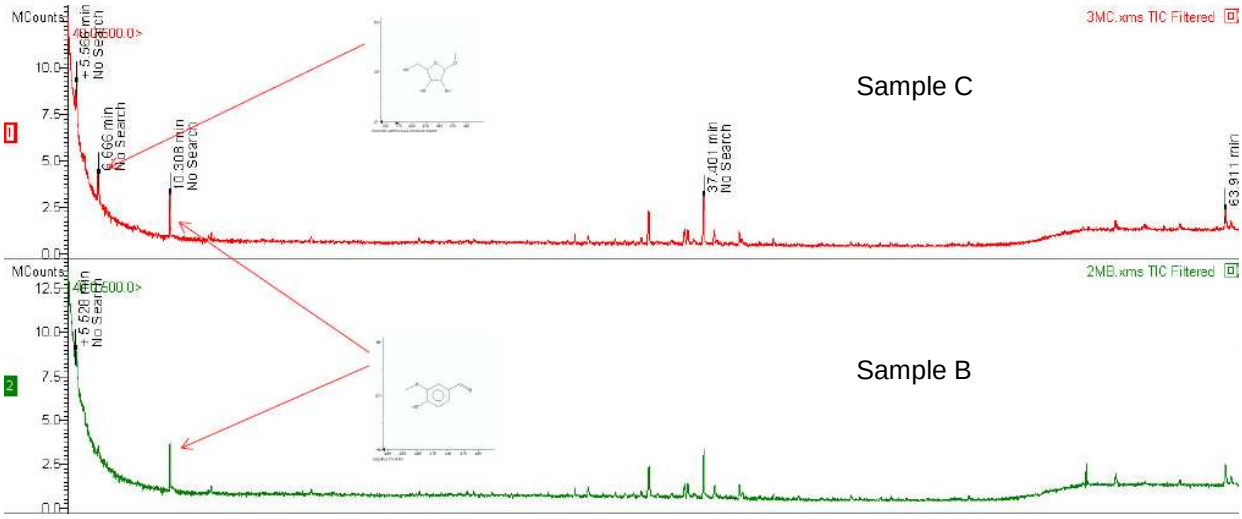
Fig 6 – Interfacial Tension changing according to the time up to 3 months

3.3 Discussion of Test Results

The target of the test run was to show the compatibility of pressboard with transformer oil. Expectation was that the values of the oil would show stronger degradation if pressboard is present (see Table I). The results of this testing showed an unexpected behaviour of Dielectric Dissipation Factor, Resistivity, Interfacial Tension and even Acidity (see Fig 2, 3, 5 and 6).

The expected trend of results of DDF (Dielectric Dissipation Factor) in the board sample (oil/board) was an increase of DDF (Dielectric Dissipation Factor). But in reality the DDF (Dielectric Dissipation Factor) of the “Board Sample” (oil/board) was always lower than the related “Blank Sample” (oil). A relevant trend was found with Resistivity; decrease of Resistivity was expected. But the test showed an increase of Resistivity. Especially interesting trend showed the results of the Interfacial Tension Test. This test is one of the most sensitive tests that is providing us with information about the property of transformer oils in service especially regarding a potentially sludge precipitation, and we expected lower values of IFT (Interfacial Tension) of the “Board Sample” (oil/board) than of the “Blank Sample” (oil). The trend was opposite and therefore we did some more investigations related to this.

The first step was an investigation of furanic compounds. Two samples were investigated Sample B (1day 23℃) and Sample C (14 days at 100℃). Sample B did not show any furanic compounds but showed only a certain amount of Vanillin (Graph 1 bottom diagram). Sample C showed only Methyl-d-Ribofuransoside which is an intermediate product during the formation of furanic compounds (Graph 1 top diagram).



Graph 1 - GC MS diagram of Sample B and C

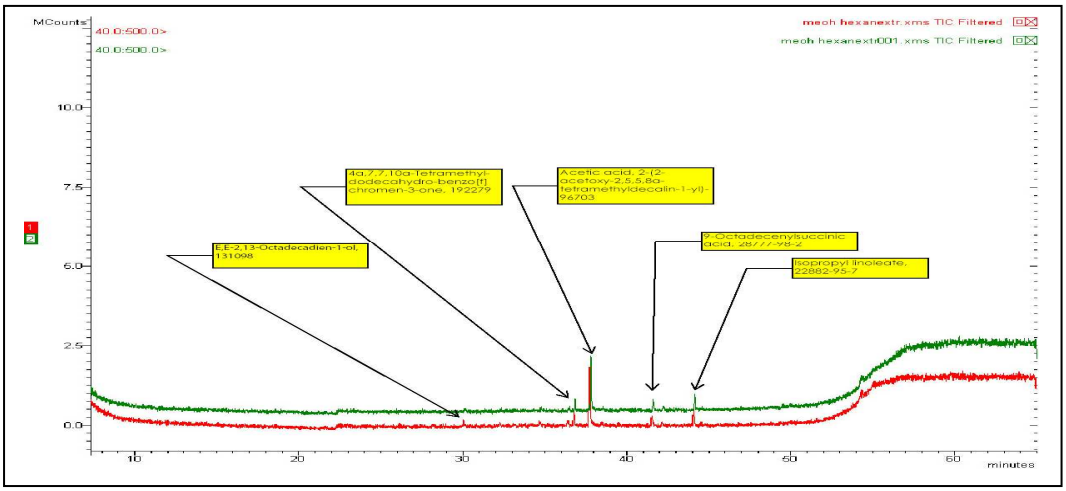
As there was no real difference concerning IFT (Interfacial Tension) we assumed that the oxidation was too little to create detectible quantities of IFT (Interfacial Tension) lowering substances.

Therefore next trial was the usage of stronger oxidized oil with IFT (Interfacial Tension) value 17,3 mN/m (Acidity 0,083 mg KOH/g). This oil has been contacted with pressboard in the following way: 100 ml of this oil was mixed with 1 gram of new pressboard (gently shaked 5 minutes, rest time: 3 hours at room temperature). After this procedure IFT (Interfacial Tension) has increased 26,2 mN/m (Acidity 0,077 mg KOH/g). This is a tremendous increase of IFT (Interfacial Tension), whereas Acidity did not change as dramatically.

Obviously in this case the pressboard absorbed some substances from the oil thus increasing the IFT (Interfacial Tension) of the oil. We therefore extracted the pressboard with several solvents and these eluates have been investigated by GC-MS. The found substances can be characterized as polar oil oxidation products that are lowering IFT (Interfacial Tension) as follows.

Table II – Extract and Found Substances from oil Impregnated Pressboard

Extract	**Appearance**	**Found Substances Name, CAS No.**
Hexane	Oil Matrix	Oil Matrix
Dichloro-methane	Yellow Brown	3,5-di-tert-Butyl-4-hydroxybenzaldehyde, 1620-98-0 9,12-Octadecadienoic acid (Z,Z)-, methyl ester, 112-63-0 11-Octadecenoic acid, methyl ester, 52380-33-3 9-Octadecenoic acid (Z)-, octadecyl ester, 17673-49-3
Acetone	Yellow Brown	Neocurdione, 108944-67-8 Ethanone, 1-[1,1'-biphenyl]-4-yl-, 92-91-1 2,4,6-Trimethoxyacetophenone, 832-58-6 E,E-2,13-Octadecadien-1-ol, 131098 Hexanedioic acid, mono(2-ethylhexyl)ester, 4337-65-9 Hexanedioic acid, bis (2-ethylhexyl) ester, 103-23-1 Diisooctyl adipate, 1330-86-5
Methanol	Clear	4a,7,7,10a-Tetramethyl-dodecahydro-benzo[f]chromen-3-one, 192279 Acetic acid, 2-(2-acetoxy-2,5,5,8a-tetramethyldecalin-1-yl)- 96703 E,E-2,13-Octadecadien-1-ol, 131098 9-Octadecenylsuccinic acid, 28777-98-2 Isopropyl linoleate, 22882-95-7
Methanol / Formic Acid	Clear	11-Octadecenoic acid, methyl ester, 52380-33-3 9,12-Octadecadienoic acid (Z,Z)-, methyl ester, 112-63-0 Oleic Acid, 112-80-1 1-Docosanol, 661-19-8
Acetone	Yellow Brown	9,10-Anthracenedione, 2-(1,1-dimethylethyl)-, 84-47-9 Oil matrix
Acetonitrile	Clear	-
Methanol	Clear, Yellow Brown	Podocarp-8(14)-en-15-al, 13à-methyl-13-vinyl-, 472-39-9 Ethyl pimarate, 57274-58-5



Graph 2 - Accumulation of the polar oil substances of the second test series and Extraction to search for missing (absorbed by pressboard) substances in the treated oil.

Table III – Extract and Missing Substances in the Pressboard

Extract	**Appearance**	**Missing Substances in the Pressboard-treated Oil Name, CAS No.**
Hexane	Oil Matrix	Oil Matrix
Dichloromethane	Clear	-
Acetone	Yellow, Brown	-
Methanol	Yellow, Brown	E,E-2,13-Octadecadien-1-ol, 131098
Methanol / Formic Acid	Clear	-

Octadecadieon-1-ol was found as missing (possibly absorbed by pressboard) substance in the Methanol extract. This substance has the potential to affect Interfacial Tension due to its amphiphilic (hydrophilic and lipophilic) character. At this place it should be mentioned that this test can not make a claim to be complete, because just noticeable differences can be seen. That means that most of a specific substance must be absorbed to see the missing part via GC-MS.

4. CONCLUSIONS

The investigation showed a strong not only negative impact of pressboard to the oil but as well a certain and very interesting positive effect in a combined system of pressboard and transformer oil.

The result is that the pressboard is acting like an adsorption filter that is extracting some polar substances from the oil leading to better values of DDF (Dielectric Dissipation Factor) and IFT (Interfacial Tension) in such combined system for certain period. There is further investigation necessary to get more knowledge about these compounds and their possible effect on the combined system.

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