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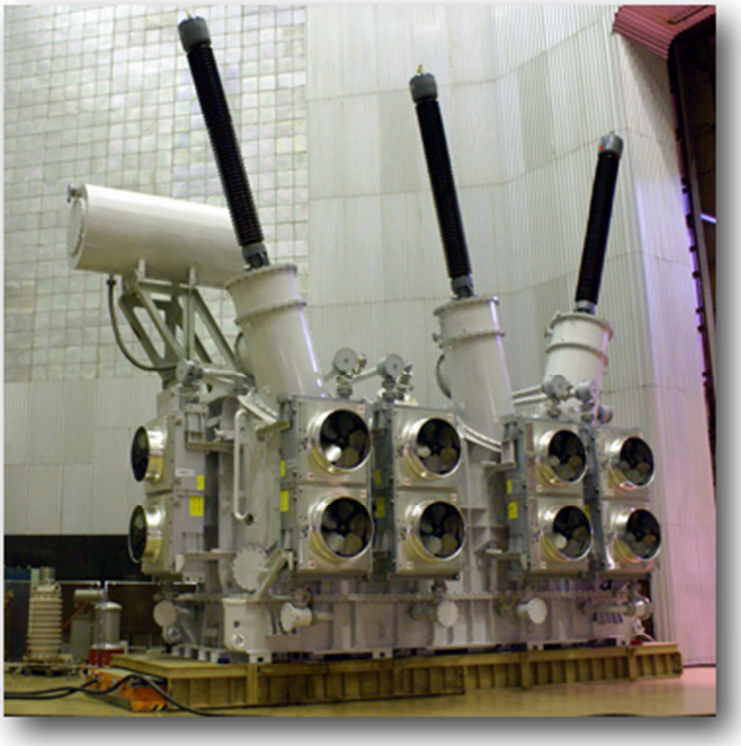

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HV Insulation Materials and Components Properties From The Perspective of Laboratory Tests

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ABSTRACT

Transformers and Reactors are the crucial elements of electrical structures which make insulation systems significantly important factor. It is extremely necessary to emphasize the importance of a reliable insulation system in modern power transformers. Insulation failures are always the most common and expensive ones among transformer problems. Due to high short-circuit power levels in today's electrical networks, a breakdown in transformer insulation will always result in a major damage in transformers.

Insulation design in power transformers is related directly to the quality of pressboard and transformer oil. Studies how the transformer oil affects pressboard material and how pressboard material affects transformer oil, together with related compatibility tests have been conducted, and experiments with contamination tests of oil have been planned and carried out.

Additionally, several standards and sources had been studied, concerning how mechanical, chemical and electrical tests of pressboard, laminated pressboard and components should be carried out.

INTRODUCTION

The substances used for the purpose of insulation in transformers and reactors are cellulosic pressboard and transformer oil. In this study the interaction of these two substances, relation between them has been analyzed according to IEC, ASTM or standards of some transformer manufacturers.

Besides the effect of the insulation materials between each other, electrical strength tests were performed on HV insulation components made of cellulosic material. These tests were carried out at the most critical areas of HV insulation components. For instance, cylinder (barrier) and angle ring sector overlap (joint) areas.

In addition, some examination was made on laminated board with Polyester which is used for production of press rings increasing the mechanical stability of transformer.

MATERIALS AND CRITICAL HV INSULATION COMPONENTS FOR POWER TRANSFORMERS AND REACTORS

Pre-Compressed "Pressboard"

Pressboard impregnated with transformer oil under special conditions (vacuum, temperature and time) is known to be the best insulation material for high voltage transformers and reactors. The mixture consisting of pure cellulose and pure water is converted to firstly pulp then to paper with 75% water and finally to pressboard under special temperature and pressing process. It's requisite and essential to manufacture and control in accordance with IEC 60641. The main tests according to IEC 60641-2 can be listed as follows;
Thickness, density, tensile strength, elongation, shrinkage, compressibility, conductivity, pH, oil absorption, water content, ash content, electrical strength.

Besides these tests, oil compatibility test should be conducted.

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

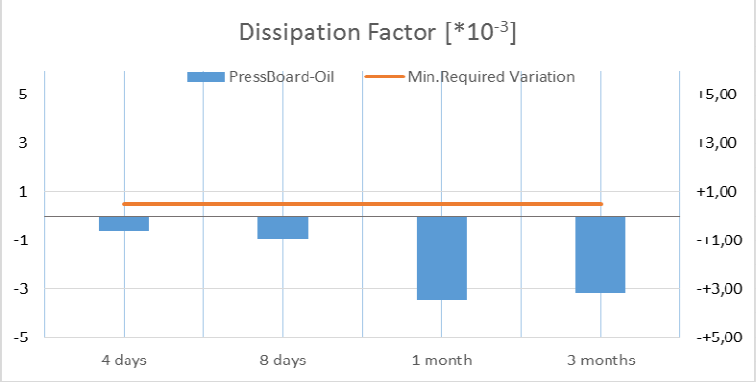
The following criterions have been tested and measured on the oil before and after the relevant test duration.

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

Table I - Variation Limits for Oil Compatibility

Test / Property	Unit	Transformer Manufacturer		ASTM D 3455	
		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°C)	[---]
Resistivity at 90°C	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	[---]

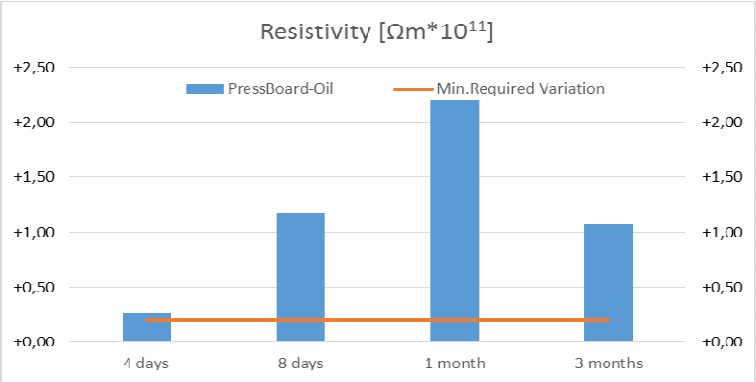
Dielectric Dissipation Factor [*10^{-3}]



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.

Figure 1 – Dielectric Dissipation Factor changing according to the time up to 3 months

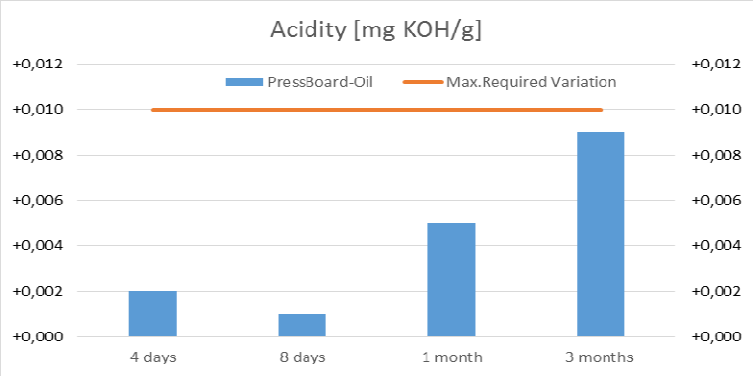
Resistivity [*10^{11} Ωm]



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

Figure 2 – Variation of resistivity with time up to 3 months

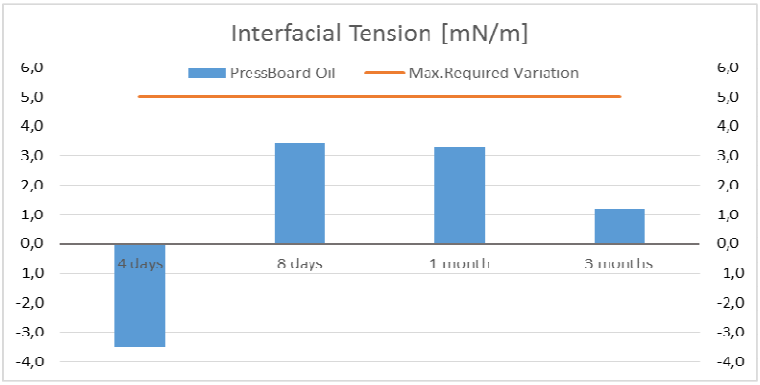
Acidity [mg KOH/g]



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).

Figure 3 – Variation of Acidity with time up to 3 months

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 additional information together with other oil tests.

Figure 4 – Variation of Interfacial Tension with time up to 3 months

This test showed a perfect compatibility of pressboard material and 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.

Laminated Pressboard

Pre-compressed pressboard is a very high mechanically enduring material fulfilling the need of thick insulation material in transformers and combined of pressboards by the help of aqueous (Casein) and non-aqueous (Polyester) glue types. It's requisite and essential to manufacture and control complying with IEC 60763. The products made of laminated pressboard material, particularly the materials produced using Polyester glue may cause partial discharges in a transformer. For this reason especially Partial Discharge Inception Voltage (PDIV) tests must be performed. The conditions and results of the test are as below:

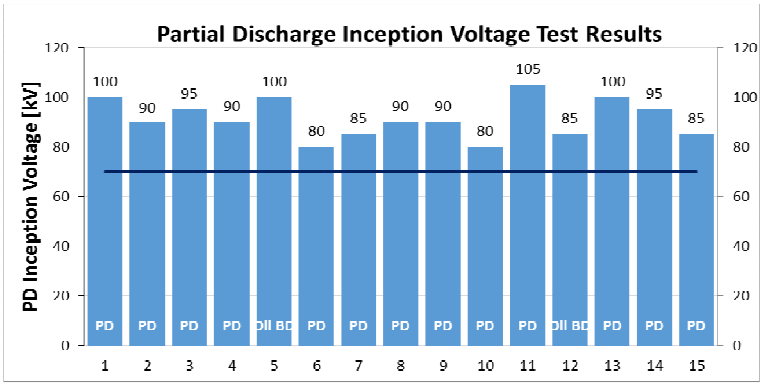
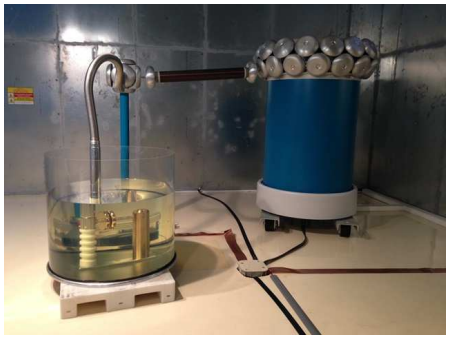


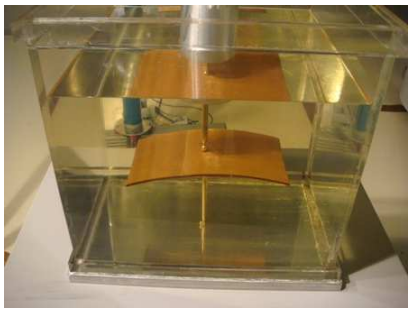
Figure 5 – Partial Discharge Inception Voltage Test Results



Circuit of PDIV Test

Cylinders

It is a critical product in terms of mechanical and electrical strength between LV and HV windings. The most important area of this product is the overlap area. The electrical strength value at this area must not be lower than the other solid areas.



Electrode Configuration of Electrical Strength Test

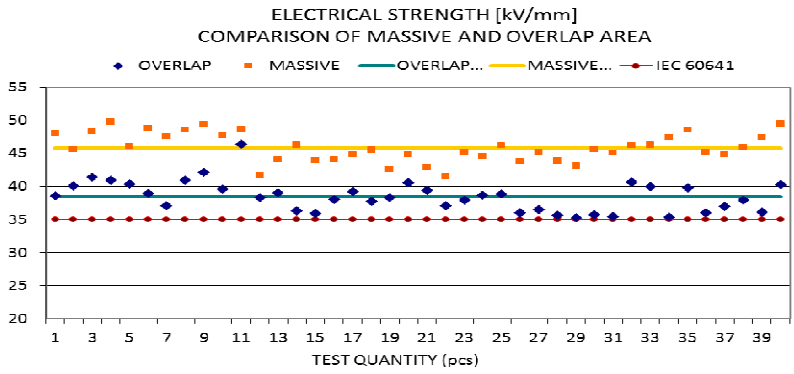


Figure 6 – Breakdown Voltage changing according to Massive or Overlap area

Snout (Chimney Sector) and Angle/Cap Rings

Snouts and Angle/Cap Rings are of primary importance used in transformer as insulating materials. Copper cables, output of HV windings pass through these materials before getting connected to the network. Therefore, these products which have specific geometries may have various types.

Besides a whole ring shape it can be produced and used as a ring combined of sectors with overlap areas. The electrical strength at overlap areas must be higher than the acceptance value *20 kV/mm. (*This value does not exist in IEC standards. It is an acceptance value established by some transformer manufacturers.)

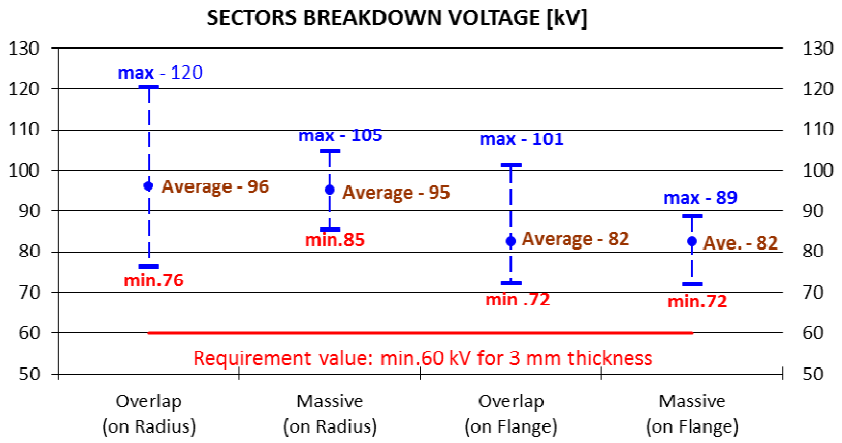
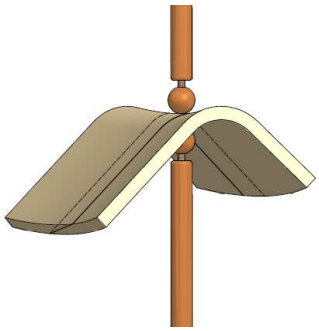


Figure 7 – Breakdown Voltage changing according to Massive or Overlap area



Electrode Configuration (IEC 60243)

CONCLUSION

This study focused on relation between cellulosic insulation materials and transformer oil, partial discharge level of laminated pressboard and electrical strength results of various HV insulation components.

The findings are given below;

- 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.

- The partial discharge initial voltage level may increase or decrease with the quality of pre-compressed pressboard which is used in the production of laminated pressboard and the amount of air bubbles in the glued area between two pressboards. For this reason the partial discharge results may be good or bad during acceptance tests of transformer or for transformers in service.

- The most critical areas of insulation components are overlap (joint) sections. The production process of a component used in this section must be very stable. The geometrical compatibility of two parts to be overlapped is essential. In case of an incompatibility at this section, electrical strength values may be lower than the criterions of design.

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BIOGRAPHY

Faruk ERENLER has been employed at ENPAY since 2004, and currently works as a Manager in the HV Insulation Components Quality Control. He is CIGRE Observer Member on the SC D1: Materials and Emerging Test Techniques. Mr. ERENLER received his 2001 Bachelor of Science Kocaeli University - Kocaeli/TURKEY, Faculty of Engineering - Electronics and Communication Engineering.

Qualifications and professional experience when relevant.

- Production and Quality of High Voltage Insulation Components
- Production and Inspection of Pre-compressed Pressboard
- Production and Inspection of laminated pressboard with casein and Non-aqueous (Polyester, PVA etc.) Adhesive
- Internal Auditor - ISO 9001 and ISO/IEC 17025
- Design of 400-550kV Exit Insulation System.
- Managing and performing pre-compressed pressboard laboratory tests according to IEC 60641
- Managing and performing laminated pressboard laboratory tests according to IEC 60763

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