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` The Quality Aspects of Solid Insulation in Power Transformers and Reactors'

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The Quality Aspects of Solid Insulation in Power Transformers and Reactors

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Abstract: This paper presents some laboratory test results of new pressboards taken from production unit and service-aged pressboards taken from a failed power transformer after 27 years' service. Furthermore, presents relation between the pressboard and transformer oil.

Keywords: Pressboard, Laminated Pressboard, Transformer Oil, Degree of Polymerization, Ash Content, Conductivity, Dielectric Dissipation Factor, Acidity, Interfacial Tension Test

I. Introduction

The life of Transformers depends on the life of Insulation. The solid Insulation in liquid immersed Power Transformers is cellulose based material . It is still the best and the most cost effective insulation. Many different types and levels of quality of Pre-Compressed Pressboards are produced. However, the chemical, physical and electrical parameters of these materials must be assured and controlled by tests such as Degree of Polymerization, Conductivity and Ash Conent etc. according to IEC standards. Pressboard quality depends on the state-of-the-art technology which shows us in following curves. Following tests must be carried out in order to understand relation between the transformer oil and pressboard; Acidity, Dielectric Dissipation Factor (DDF - Tan Delta), Interfacial Tension tests. [1]

II. Solid Insulation Material (Pre-Compressed Pressboard)

The basic necessity for this test is the simple fact that Pre-compressed Pressboard is used in The HV – UHV Power Transformers. Besides sensitive testing**,** one must ensure the sustainability of good quality manufacturing and quality systems. We concentrate on the Quality of Pre-Compressed Pressboard. The raw material of that must be in good quality of unbleached sulphate cellulose pulp and the manufacturing must be performed with hot press process in a very clean environment. [1, 2]

Insulating material within a transformer must be able to 1) separate the different electrical circuits; 2) isolate the transformer core and outer case from the electrical circuits; 3) provide mechanical support for the electrical coils within the transformer during transportation and operation; 4) withstand the mechanical forces imposed by power system surges and short circuits; 5) dissipate heat; and 6) be environmentally safe. [3]

IEEE Std.-C57-91-1995 – Subclause 3.5.Transformer insulation life: For a given temperature of the transformer insulation, the total time between the initial state for which the insulation is considered new and the final state for which dielectric stress, short circuit

stress, or mechanical movement, which could occur in normal service, and would cause an electrical failure.[4]

Precise testing facilities and extensive quality controls according to IEC 60641 standards are essential in order to guarantee the best quality. Pre-Compressed Pressboard quality depends on the state-of-the-art technology. Some important properties of Pressboard were researched and obtained values are shown in the following benchmarking curves related with Indian production pressboards. ENPAY laboratories are international accredited according to ISO/IEC 17025. [5]

Degree of Polymerization (DP);

Stages for Life of Cellulose & Pressboard	DP
Cellulose	1300…1400
Pre-Compressed Pressboard	1100…1300
Insulation Components	1000…1100
After Active Parts Drying Process	800…1000
End Of Life	≤ 200

Table 1. Stages and DP Values for Cellulose, Pressboard, Components and end of life components

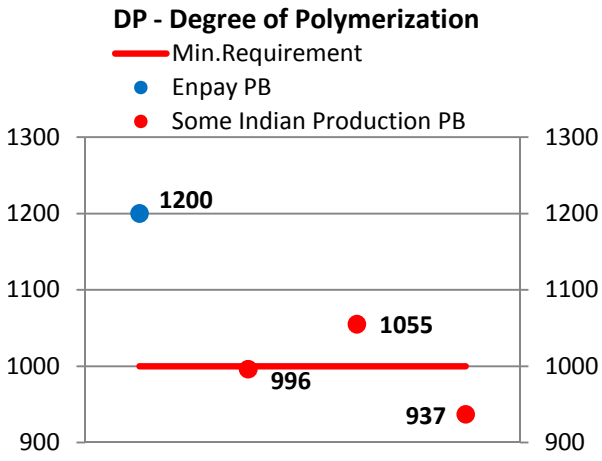


Fig.1. Comparison of degree of polymerization for high density pressboard and made in India Pressboard. PB: Pressboard

Degree of polymerization should be in high value for long life transformer. This proves to be the most informative parameter for assessing the ageing or the process of ageing of cellulose . The connection between deterioration in material properties and formation of aging products is degree of polymerization.[6]

Ash Content;

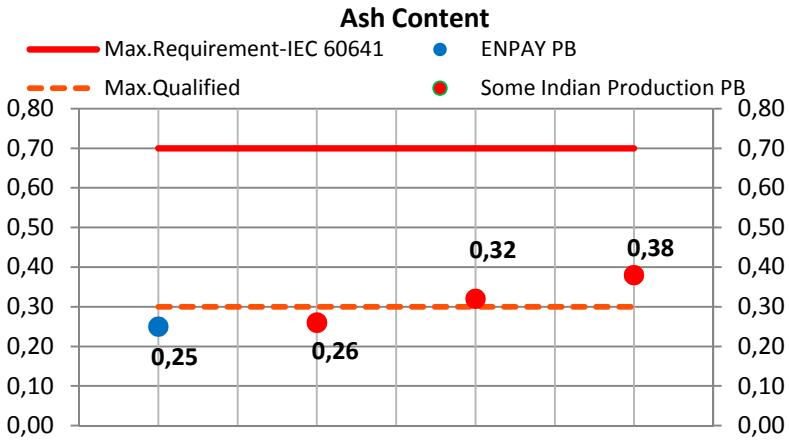


Fig.2. Ash Content obtained value according to different qualities of pressboard. PB:Pressboard

The transformer oil is contaminated particularly by copper, magnetic steel and insulation components in transformer. A large part of the pollution in Transformers is caused by BAD QUALITY cellulose-based materials. High-quality pressboards of which raw cellulose should have lower ash content and very high purity must be used in transformers.

Conductivity;

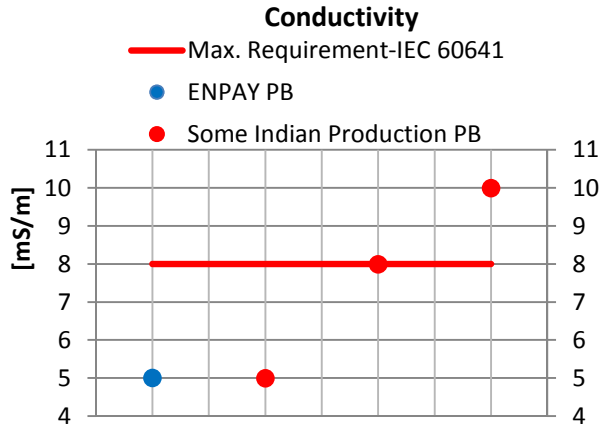


Fig.3.Conductivity that can affect early Partial Discharge on surface – PB: Pressboard

The source for the insulation conductivity is the presence of impure ions. The movement of the ions increases with the rise of the temperature. The active centers of cellulose molecules "attract" the ion impurities and by doing so they "restrict" their movement.[7]

Presence of Metallic Particles;

This test is performed in order to understand how much of the material is pure. Electrical strengths of impure pressboards are lower than pure pressboards and impure pressboards comtamination ratio is higher than pure pressboards. The following photos indicate pure and impure pressboards.

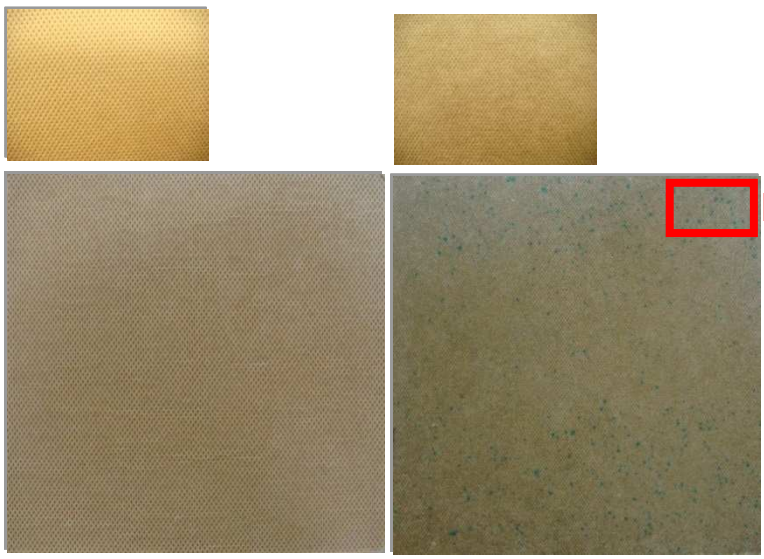


Fig. 4. Pure Pressboard

Fig. 5. Impure Pressboard (from India Market)

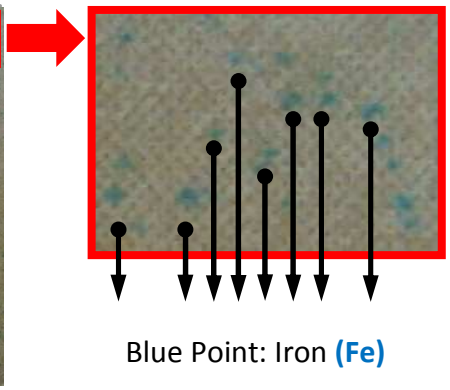


Fig. 6. Blue points are Iron particles

The metal particles in the board directly contaminate oil and winding insulation and by this way the life of transformer gets shorter. This situation is one of the most important problem in the pressboard manufactured in India.

It is also of paramount importance that the inter-relation of the Pre-Compressed Pressboard and oil is examined in great detail. Oil and Pre-Compressed Pressboard are affected from each other. In order to check the behavior of Pre-Compressed Pressboard and oil during the life of transformer in service, contamination test should be carried out.[8,9]

Several standards and sources had been studied, concerning how compatibility tests of oil and Pre-Compressed Pressboard should be carried out; differences were observed in some basic conditions, sample preparation, etc. and test series were performed in order to find the most suitable test method.

Pre-Compressed Pressboard and oil are aged under defined temperature for a certain period and afterwards some criterions are measured (Color, Resistivity, Dielectric Dissipation Factor, IFT (Interfacial Tension), Acidity)

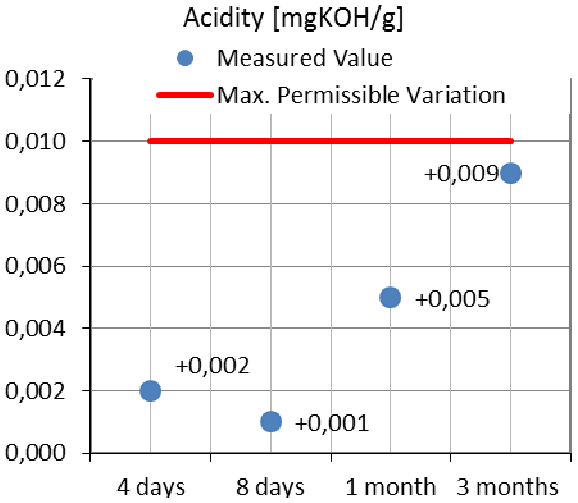


Fig.4. Acidity is indicator of pollution of transformer oil. (Permissible variation is acc.to transformer manufacturer)

The increase of value of acidity in transformer oil causes rapid aging of all cellulose materials in transformer in the long term.

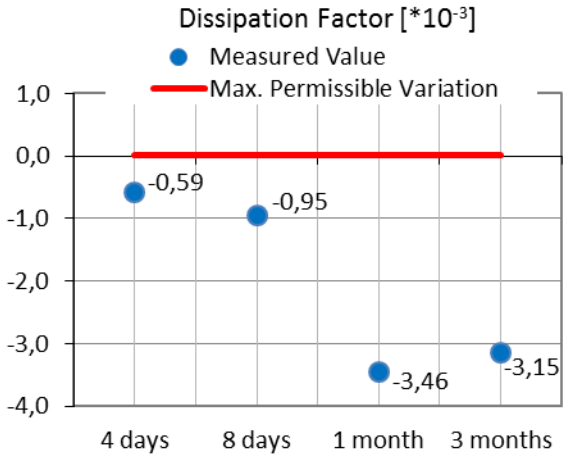
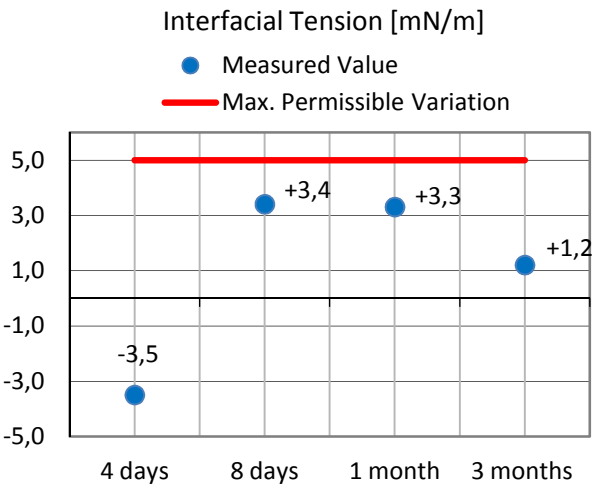


Fig.5. DDF is required to give the final decision on transformer oil.
(Permissible variation is acc. to transformer manufacturer)

Dissipation factor is closely related with cellulose quality and cellulose of poor quality usage causes increase in Dissipation Factor of transformer oil and accelerates sloughing of transformer oil.



Decrease of Interfacial Tension value shows not only the increase of contamination but also the sludge formation in transformer oil.

Fig.6. IFT values as function of the transformer oil pollution quality.(Permissible variation is acc. to transformer manufacturer)

Generally for this research, a deterioration of the oil is expected. 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.

III. Solid Insulation Material (Laminated Pressboard)

Pre-Compressed Pressboard is manufactured at a maximum thickness of 8,0 mm. Therefore, due to thicker insulation materials necessity in transfomer, Laminated Pressboard in accordance with IEC 60763 is demanded. These materials are glued using Casein or Polyester based adhesives. Particularly, products such as press rings, press wedges, shield rings, cable carriers, lathes are manufactured of Laminated Pressboards. These products are expected to be mechanically durable, dimensionally stable and also should not get delaminated after active part drying processes. This conditions are considerably important regarding high voltage technical issues and costs of transformers.[10,11]

It can be said that Laminated Pressboard has much higher partial discharge inception voltage, better drying and oil impregnation feature, better aging behavior compared to Laminated Wood. It has been observed that Laminated Wood gives out corrosive acids during drying process in oven. As alternative to Laminated Board it has many negative points especially in HV Power Transformers such as mechanically deterioration is more rapid.

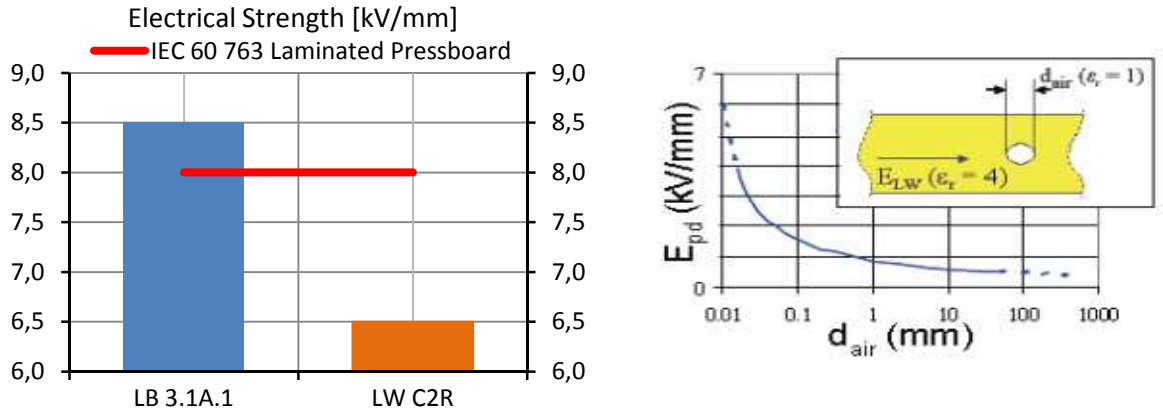


Fig.7 and 8. Electrical Strength and PD-inception field strength of oil impregnated Laminated Wood as a function of the size of an air-filled void.

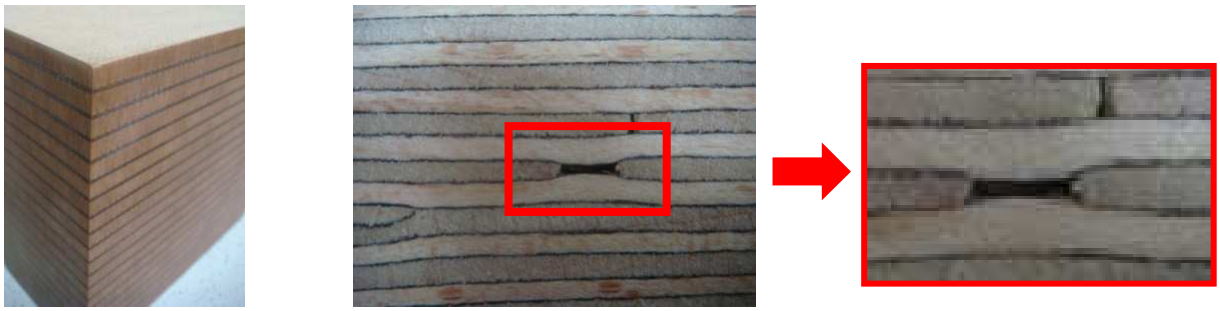


Fig.9. Laminated Pressboard without void – Fig.10.and 11. Laminated Wood with air-filled void

Laminated Wood is produced by joining sheets of wood veneers (typically beech) together with a thermosetting synthetic adhesive (typically phenolic) under pressure and heat. Always, Laminated Pressboard electrical strength results are higher than Laminated Wood results since Laminated Pressboard material do not have air-filled void. [12]

IV. Insulation Components for HV and UHV

It is a fact that optimized design of the Insulation Systems and use of modern insulation components reduce the cost of Power Transformers significantly. It is not necessary to compromise the quality and volume of transformers. A reduction of the oil volume and in consequence a smaller transformer size can be achieved as a result of using optimized Insulation Systems.

HV Insulation Components and Lead Exit Insulation Systems are most important parts of transformer insulation. We can say that “Lead Exit Insulation Systems” and shields are major causes of failures of solid insulation in transformers. If we consider the reasons of these failures we can see that the thick layer of paper wrapping lies at the center of the problem. Best solution is proved out to be Lead Exit Insulation Systems with barriers. Total costs compared with conventional types are actually less. On the other hand it can be said that Transformers with Barrier System (Lead Exit Insulations Systems) have longer lives.

Barrier systems provide major advantages same as lead exits, in terms of optimization with perfect dielectric strength and make whole system safer. Lead Exit Insulation Systems without barriers only with paper wrapped conductor and single wide oil gap has many disadvantages compared to the state-of-the-art barrier systems.[1, 2]

Fig.12.Cylinders

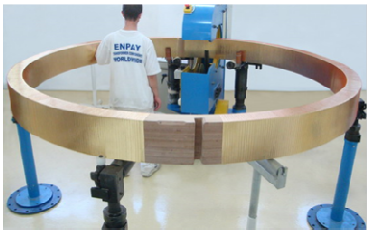


Fig.13.Shield Ring – Static Ring - Schirmring

Fig.14. 1200 kV Lead Exit
BIL: 2300 kV – SIL: 1675 kV
(for inside of tank design)

V. Case Study

This case study was carried out on the power transformer of Natural Gas Combined Cycle Power Plant between the 1985 – 2012. This transformer has run for 27 years without any problem. But in 2012 due to a problem on the bushing of 3 phase power transformers, a short circuit has occured on Lead Exit Insulation Systems.

This case study is performed to see the exchange of the mouldable components such as angle ring in terms of the physical (tensile strength) and chemical (degree of polymerization) properties. Degree of polymerization and tensile strength precision tests were selected for research. The obtanied values include physical and chemical properties are given in the following figures.

About Power Transformer:
Produced by: Mid European Producer
Year of Manufacture: 1985
Nominal Voltage and Power: 400 - 10,5 kV / 125 MVA
Transformer Oil: Technol Export 2000

Fig.15. Photos of short circuit insulation components in this Case Study

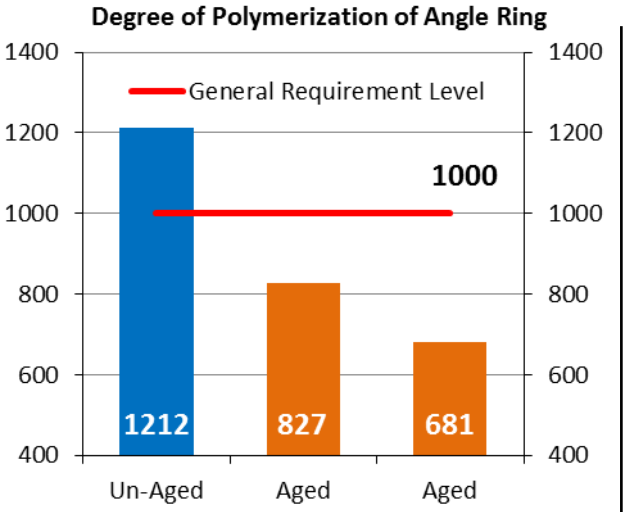


Fig.16.Un-Aged/Aged Angle Ring Degree of Polymerization

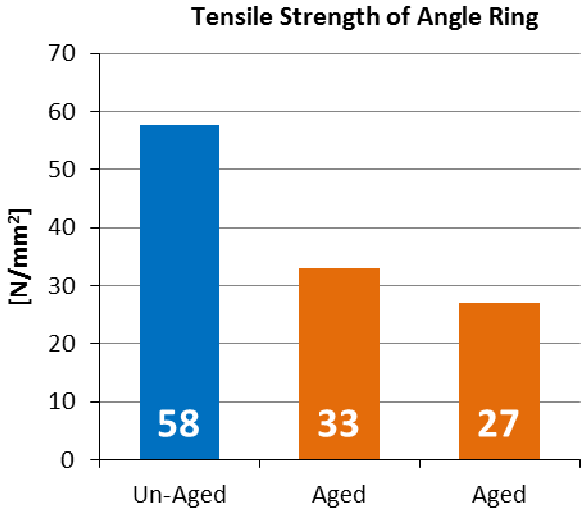


Fig.17.Un-Aged/Aged Angle Ring Tensile Strength

Degree of Polymerization and Tensile Strength are related to each other. Tensile Strength values depend on degree of polymerization value. If DP value decrease then Tensile Strength value will decrease. Tensile strength value is very important in terms of mechanical support for the electrical coils within the transformer during transportation and operation and to withstanding the mechanical forces imposed by power system surges and short circuits.

As a result, we can say that degree of polymerization and tensile strength values were decreased approximately % 40 in 27 years.

VI. Conclusions

This study describes the optimization procedure of high-voltage winding insulation materials in an oil immersed power transformer. With the help of various significant tests performed in the laboratory, substantial information for the incoming control and winding design is provided which in turn increases the insulation reliability.

It should be noted that 100 % pure cellulose and pre-compressed pressboard must be used in order to avoid early contamination of winding insulation in power transformer and reactor.

Degree of Polymerization, Conductivity, Ash Content, Presence of Metallic Particles, Contamination of Oil Tests (DDF, Acidity, IFT), Electrical Test results should be in accordane with the required levels in related standards. This plays an essential role to have a longer life time in a transformer.

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