International Journal of Mechanical and Industrial Engineering

Volume 2 | Issue 4 Article 6

April 2013

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AGEING RATE OF PAPER INSULATION IN TRANSFORMERS ON ITS MECHANICAL STRENGTH

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Abstract: It is well known that the paper and oil used in transformers Degrade with time at rates which depend on the temperature and the amount of air and water present [1, 2]. Various devices such as completely sealing the units, using nitrogen blankets and using flexible membranes, have been suggested as means of improving the lifetime of the oil. In addition, thermally upgraded papers have been devised and have been available for some years. Some supply authorities and transformer manufacturers have been using some or all of these devices with varying degrees of success. Many others have taken the stance of cautious awareness. In the absence of any evidence that normal papers are inadequate, they have continued to use them in transformers fitted with conservators. As part of this current overall package of research, paper aging was re-examined with a view to reassessing the need for change, either in the materials or practices
Used or in the preservation systems.

Keywords: *Transformers, moisture content, thermal aging, Insulation, water content; degree of polymerization*

1. INTRODUCTION

As part of a comprehensive study of transformer behaviour, the factors which control the aging processes in transformer paper have been reviewed experimentally. Three different types of paper have been used: 60/40 manilla/wood, all-wood and thermally upgraded paper. Aging has been done *in vitro* under oil in atmospheres of nitrogen and air with controlled water contents. The aging temperatures were in the range 110-140°C with aging periods up to 1.5 years. Paper condition was monitored by measuring its degree of polymerisation (DP) checked by burst strength. In most of the experiments normal BS 148 oil was used, but some experiments were done to examine the effect of oil preservatives on paper aging. Opportunity was taken to compare the furfuraldehyde contents of oils from the aging cells with paper condition. It is confirmed that paper aging is highly dependent on temperature and the presence of water and oxygen, although the aging of the thermally upgraded paper examined is virtually unaffected by water and only slightly by oxygen.

2. PAPER AND ITS DEGRADATION

The main source of cellulose fibres is wood, and the preparation of woodpulp, used to make paper, is a process which removes most of the other constituents of the living plant, e.g. lignin, carbohydrates, waxes etc., to leave the cellulose fibres. Manilla fibre is also used. This is extracted from the palm-like leaf stalks of the Manilla hemp plant (Musa Textilis) which grows in the Phillipine Islands. Its primary use is to make ropes or textiles depending on its fineness, and the paper pulp is often produced from used cordage (old rope). Cellulose is a linear polysaccharide consisting of anhydro D-glucopyranose units held together by a ($-linkage. Many of these long chains form a single cellulose fibre.

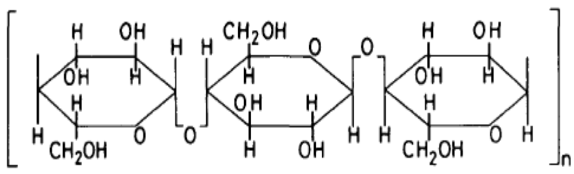

Fig. 1 *Cellulose structure*

In this article, we show the influence of air and oil type (inhibited, non-inhibited) on the aging of pressboard under the influence of a considerable amount of moisture. (At an initial content of 3.9% moisture, the solid insulation of a transformer would be classified as wet.) The rate of the degree of polymerization, the development of furanic compounds, as well as the gas-in-oil analysis in comparison with the aging of the pure oil under the same conditions have been investigated.

3. MOISTURE EQUILIBRIUM CHARTS

To check the dryness level in transformers whether in the factory or the field, dew point measurements are widely used. Dew point is the temperature at which the vapor pressure of water at a given temperature becomes equal to the saturated vapor pressure. These may be constructed from the Piper charts and vapor pressure-temperature data [2]. Usually the transformer manufacturer provides a diagonal pass/fail plot of ambient temperature of equilibration versus dew point, which may represent the acceptable dryness level (e.g., 0.5% moisture). Dew point measurements are conducted before the unit is shipped by equilibrating the transformer interior with dry air or nitrogen; and, after sufficient time, the dew point is measured at the ambient temperature. In the field, the same procedure is applied. It must be remembered that oil-impregnated insulation needs a much longer time (as much as 20 times) than the time for oil-free insulation to reach moisture equilibrium between the gas space and the solid phase.

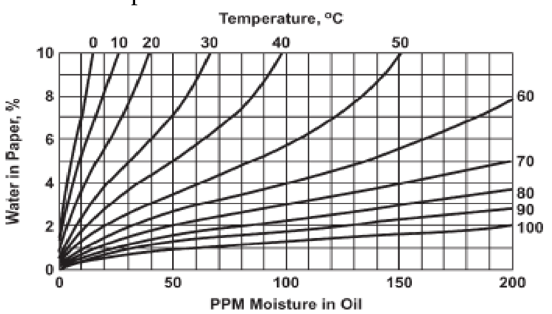

Fig2: Moisture Equilibrium chart

However, wet oil (usually judged by parts per million moisture in oil, but should be based on relative saturation) does not always mean a wet insulation. As a transformer cools down due to load reduction or shut down, moisture tends to return to the paper, but this process is slow. Hence, there is a moisture buildup in the oil, giving the impression of a wet transformer. The truth is, such variations in oil moisture content hardly affects moisture content of paper, which remains fairly constant. This is not surprising because more than 99% of the water is in the solid insulation. The moisture in the oil could be a true indicator of the moisture in paper only if the paper and oil are in thermal equilibrium, which almost is never the case in operating transformers. Nevertheless, equilibrium curves such as shown in Figure 2 constructed from moisture sorption data on paper and oil [4], [5] are used often to get an idea of paper moisture content.

4. MONITORING METHODS

The degradation process can be followed in many different ways such as tensile, folding, tear and burst strengths, by gas evolution and electrical properties, or by copper number, acidity, degree of polymerisation and degradation factor. There is usually good correlation between the tests [6]. The degree of polymerisation (DP) [7] is used as a measure of degradation in this paper, although burst strength was also always measured as a cross-check. The two properties were found closely correlated for a given paper down towards brittleness. This step of making two measures of degradation was done to support the assumption that the various aging conditions (e.g. air/no-air, dry/ wet, gas-stagnant/flushed) all produced a similar type of degradation for the different papers.

Most of the early work, such as that of Montsinger [8], was based on the use of tensile strength as a measure and taking as a criterion for the end of 'useful life' the reduction of the tensile strength to 50% of its original value. The more precise DP method gives the same information more conveniently. Fig. 3 shows how paper loses.

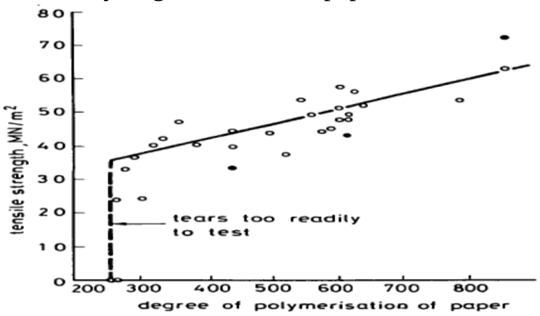

Fig 3: Tensile strength and DP of papers from model transformers

5. RESULTS GAS-IN-OIL ANALYSIS OF PRESSBOARD –OIL SYSTEM

The oil-pressboard system developed more hydrogen compared to the pure oil system at the beginning of the aging as can be seen in Figs. 4-6. With the further aging the hydrogen values were similar for both the oil-pressboard and the pure oil systems. The development of hydrogen may be influenced by humidity.

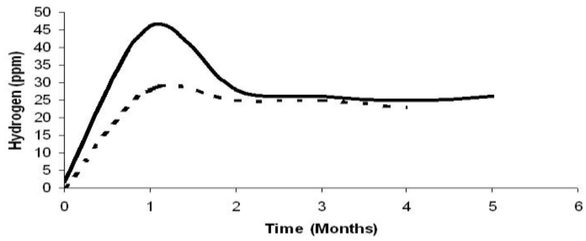

Fig. 4. Development of hydrogen as a function of time in the presence of air at 85ºC. Solid line - pressboard/oil A, dotted line - oil A only.

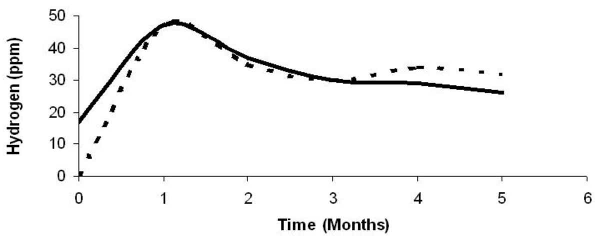

Fig. 5. Development of hydrogen as a function of time in the presence of air at 85ºC. Solid line - pressboard/oil B, dotted line - oil B only.

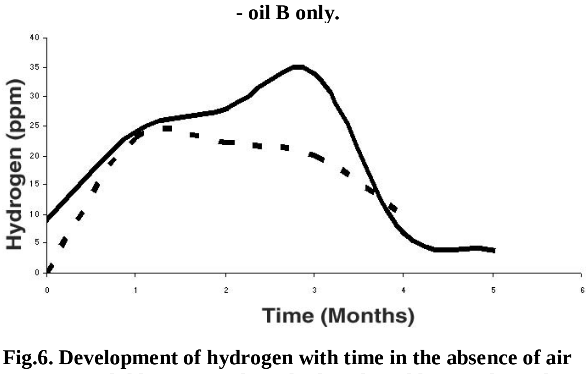

Fig.6. Development of hydrogen with time in the absence of air at 85ºC. Solid line – pressboard/oil A, dotted line – oil A only.

6. CONCLUSION

The DGA of oil/cellulosic insulation systems depends on the absence or presence of oxygen. It is also dependent on the moisture content of the cellulose. These observations require further investigations under different moisture contents.
The detection of degradation of cellulose by DGA is mainly due to the formation of carbon dioxide from the mixed insulation. The exclusion of oxygen decreases the rate of aging up to 3 fold in comparison to an oxygen-rich atmosphere.

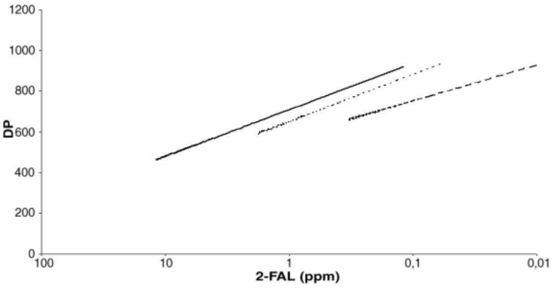

Fig. 7. DP as a function of 2-FAL under the different investigated conditions. Solid line – air, oil A, dotted line – air, oil B, dashed line – absence of air, oil A.

The application of inhibited oils in air has a certain protective influence on the solid insulation and retards aging to some extent. Under the investigated conditions (85°C, 3.9% moisture) the change of DP in air systems is more sensitive to 2-FAL development than in air-free systems. The absolute correlation of 2-FAL to DP is more complicated and is dependent on humidity, operating temperature, type of oil and paper, and design.
A general (for all cases) dependence 2-FAL/DP is not likely to exist, but it is dependent on the test conditions. At defined and steady conditions, there is dependence between 2-FAL and DP. The absolute value of 2-FAL can vary from transformer to transformer. In order to identify a failure (or a condition change) it is more important to evaluate the increase in the rates, rather than the absolute values. Further research on the dependency of 2-FAL on moisture and temperature is necessary.

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ACKNOWLEDGEMENTS

The authors would like to thank the anonymous reviewers for their comments which were very helpful in improving the quality and presentation of this paper.

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