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Estimation for the Moisture Content of Oil-immersed Insulating Pressboard Using Dielectric Characteristic Parameter

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Abstract. The prevailing method based upon the oil-paper balance curve for evaluating the moisture content in transformer pressboard is faced with serval limitations. Therefore, the aim of this paper is to report an available approach to accurate predict the moisture content of pressboard. The published researches reveal that there exists an obvious variation law between moisture content and relevant dielectric response characteristic parameter. Consequently, the variation law between moisture content and the integral value of dielectric loss factor is studied in this work. Further, the functional relationship between integral value and moisture content is established by fitting analysis. Finally, the purpose of quantitative evaluation of moisture content is realized.

Introduction

The published studies have shown that the moisture content inside the solid insulation of the transformer can determine its aging rate [1-2]. Once the moisture content increased 1% and the transformer service life will be reduced by 10 times. Therefore, how to accurately obtain the information of the moisture content inside the solid insulation is the key issue for improving the operating environment and extending the service life of the transformer.

The prevailing method for evaluating the moisture content of transformer oil-paper insulation is realized by measuring the micro-water content in the oil, and then determine the moisture content in the insulating paperboard according to the oil-paper moisture balance curve [3-5]. However, the above approach is faced with several limitations. Firstly, the moisture in the atmosphere inevitably enters the oil sample during the sampling process, which brings an obvious error to the test results. Especially when the moisture content of the oil sample is low, the impact of the above error will be more serious. In addition, in order to better determine the moisture content of the insulating paperboard, the moisture migration movement between the oil papers must be balanced. However, due to the non-uniform distribution of the temperature inside the transformer, the above dynamic equilibrium state is rather difficult to maintain.

With the consideration of the above problems, relevant scholars reported an idea for evaluating the moisture content of the solid insulation of transformers based on frequency dielectric spectroscopy technique [6]. Studies have shown that changes in the moisture content will be produced a significant alteration in the dielectric response characteristic parameters. Provided that the variation law between the characteristic parameters and the moisture content, qualitative evaluation for moisture content can be achieved to some extent. However, most of the above methods are not suitable for quantitative evaluation of moisture content. Therefore, it is still an urgent issue to be solved.

In view of mentioned challenges, the aim of this work is devoted to reporting a method for quantitatively estimating the moisture content of transformer solid insulation. In the current work, the oil-impregnated insulating paperboard with different moisture content is firstly prepared under the controlled laboratory conditions and so as to obtain the FDS curves. Afterwards, the dielectric response characteristic parameters (i.e. the integral value of dielectric loss factor) is extracted by observing the FDS curves. Finally, the paper reported an approach for quantitatively estimating the moisture content of transformer oil-immersed insulation by establishing the variation law between the integral value and various moisture content.

Experimental Platform

In order to obtain the tanδ curves of oil-immersed cellulosic pressboard discs with different insulation condition, a series of experiments under controlled laboratory conditions were performed by author [7]. In this section, cellulosic pressboard discs (12 pieces, thickness: 2 mm, diameter: 160 mm) and mineral oil (13L, the oil-paper ratio is 20:1) were used for this experiment, and the details are shown in Table 1. The pretreatment experiment scheme of oil-immersed cellulosic pressboard is shown in Figure 1. The physical and chemical parameters of the sample are shown in Table 2.

Table 1. Parameters of the materials used in the experiment

Cellulosic pressboard		Insulating oil	
Brand	Transformer pressboard	Brand	Karamay No.25 mineral oil
Manufacturer	Chongqing Aea Group Transformer Co. Ltd. (China)	Manufacturer	Chongqing Chuanrun Petroleum Chemical Co. td. (China)
Thickness	2mm	tanδ	4×10-4
TS	MD: 150.04 MPa, CMD: 57.14 MPa	Pour point	≤-45℃
Density	1.17g/ cm3	Flash point	135℃

Table 2. Physical and chemical parameters of oil-immersed cellulosic pressboard disc

No.	1	2	3	4	5	6	7	8
DP	1286	1286	1286	1286	1286	1286	1286	1286
mc%	0.98	1.84	2.53	2.76	3.62	3.85	4.51	5.49
No.	9	10	11	12	13	14	15	16
DP	356	356	356	356	356	356	356	356
mc%	1.13	1.27	1.98	2.31	2.76	3.34	4.12	4.75

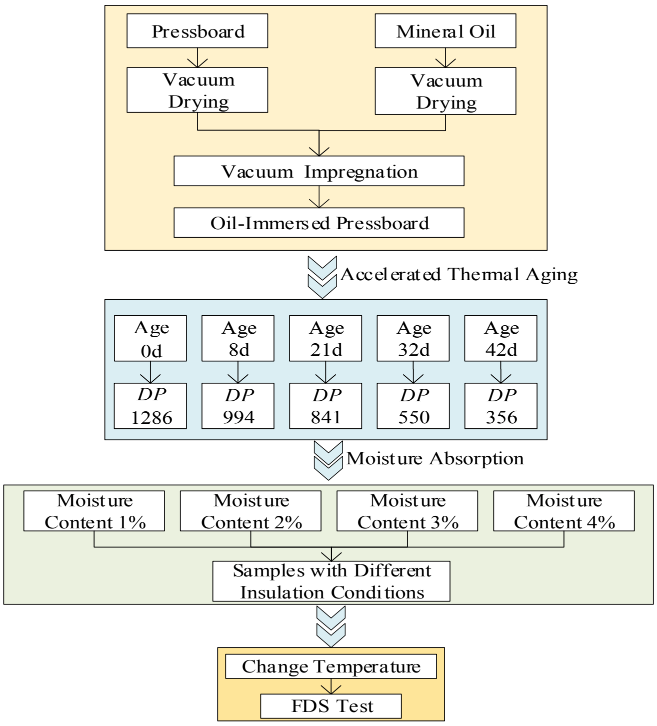
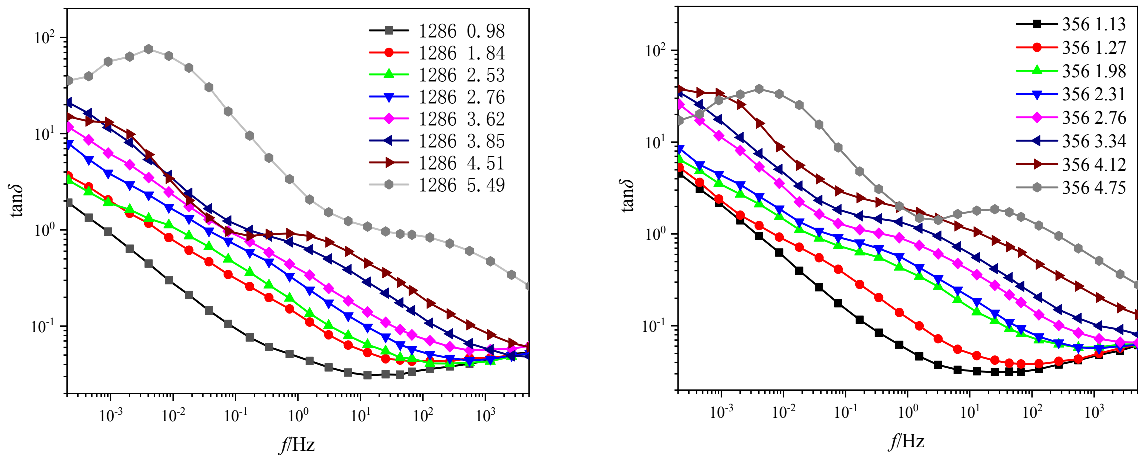


Figure 1. Scheme of the whole experiment process

Test Results and Analysis

In this paper, DIRANA was utilized to measure the frequency domain dielectric response data of different paperboards at 45 °C, where the test voltage is assigned to 200V, the test frequency is 2E-4~5E3 Hz. The tanδ curves of two kinds of pressboard including aged and new pressboards are shown in Figure 2.



(a) New pressboard (b) Aged pressboard

Figure 2. The tanδ curves of different pressboards

From Figure 2, in contrast with Figures 2(a) and 2(b), the effect of aging degree on the shape of the dielectric spectrum curve cannot be clearly distinguished, which indicates that that the effect of aging on the response curve can be covered by moisture content under high moisture content conditions.

In addition, it can be seen from Figure 2 that with the moisture content increases, the dielectric response curve increases significantly. The main reason results in the above phenomenon is that the number of ions of the oil-immersed insulating paperboard and the polar molecules increases sharply with the increases of moisture content. Subsequently, it resulting in an obvious increase in conductance loss and polarization loss. Besides, the high moisture content also promotes the accumulation of free charges, and further resulting in an increase in the interface polarization strength. Therefore, the curves move toward the high-frequency direction. In conclusion, it is estimated that the change law of the shape of the FDS curve can directly reflect the moisture content of the oil-immersed pressboard.

The Evaluation Method

As shown in Figure 2, within 10E-3~10E-1 Hz, the amplitude of the response curve is particularly pronounced. The integral values of tanδ curves are extracted so as to obtain more insulation information within a finite frequency range (Xia 2017; Liao 2015a, 2015b). the extraction formulas are shown in Equation 1.

$$S_1 = \int_{10^{-3}}^{10^{-1}} \tan\delta(f)df \tag{1}$$

The eight samples in Fig. 2(b) are selected as the research objects of this chapter, and their insulation state and curve integral values are jointly described in Table 3.

Table 3. The dielectric response characteristic parameters of samples

No.	1	2	3	4	5	6	7	8
DP	1286	1286	1286	1286	1286	1286	1286	1286
mc %	0.98	1.84	2.53	2.76	3.62	3.85	4.51	5.49
S1	0.02281	0.07016	0.09705	0.15124	0.20077	0.2731	0.23822	3.97141

It can be seen from Table 3 that the integral value of dielectric loss factor has presented a significant positive correlation with the moisture content of the pressboard, and also shows an exponential relationship. In order to verify this idea, the moisture content and the integral value of dielectric loss factor were performed the fitting analysis so as to establish a functional relationship. The fitting process is plotted in Figure 3. The fitting results showed that the obtained fitting function equation has higher accuracy, and is shown in Table 4.

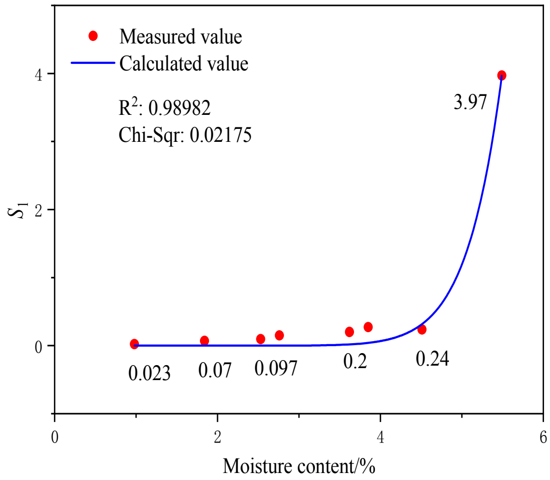


Figure 3. The fitting curve of S_1

Table 4. The fitting equation

Equation	R^2
S_1= 1.2376E-9**mc%*^ 12.853	0.98982

In conclusion, in the dielectric response curve dominated by moisture content, the effect of aging on it often can be neglected. Therefore, the equation shown in Table 3 can be used to evaluate the moisture content of insulating materials to a certain extent.

Conclusion

In this paper, oil-immersed pressboard with different initial moisture content was first prepared in the laboratory and its dielectric response curve was measured. By analyzing the influence law between the moisture content and the shape of the dielectric response curve, the authors obtained the following conclusions.

1. An increase in moisture content will make the dielectric response curve to rise throughout the full frequency sections.
2. Under the condition of the high moisture content, the effect of aging on the dielectric response curve will be covered by moisture content.
3. The integral value of dielectric loss factor shows a significant positive correlation with the internal moisture content. The functional relationship between the dielectric loss integral factor and the moisture content is established by fitting analysis. Afterwards, the quantitative evaluation of the moisture content of insulation pressboard can be achieved.

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