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Insulation Materials of Transformer Using Chemical Mechanism of Moisture Absorption

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***Abstract*—**The composite insulation system of power transformers consisting of two insulation materials (cellulose and mineral oil) are the main insulation material of power transformer, the increase of moisture will reduce their insulation strength. Moisture equilibrium curves are the basis of power transformer moisture detection, however, the service data and theory analysis both indicate the present curves are not fit for old transformer. Therefore this research work is focused the law and mechanism of the impact of aging on moisture equilibrium of cellulose and mineral oil. In this paper theory of moisture absorption mechanism and impact factors of cellulose and mineral oil are analyzed. The various aged cellulose and mineral oil samples were analysis by thermal aging method. This research work is also analyzed the moisture equilibrium law and mechanism of cellulose and mineral oil, which have been both theoretical significance and applicable potentials.

***Keywords*—** Cellulose, Mineral oil, Insulation material, Humidity condition, Aging condition, Theoretical significance

I. INTRODUCTION

With the increase of operating years, transformer gradually increasing the moisture content, moisture properties of the insulation is more significant aspects of aging between the cellulose and mineral oil balance of water, contribute to a more accurate detection of the moisture content of the transformer, has important practical value. Water between the cellulose and mineral oil balance by measuring the specific surface area of cellulose, and the interfacial tension of mineral oil and other micro parameters, studies of aging between the cellulose and mineral oil balance of water, and mineral oil to establish a moisture content of cellulose equilibrium mathematical model reveals aging on cellulose and mineral oil affect the water balance between the law and mechanisms, has important theoretical significance.

A. Research Activites

Reveals aging on cellulose and mineral oil affect the water balance between the law and the mechanisms established between cellulose and mineral oil water balance model, the existing cellulose and water balance between mineral oil aging and conditions curve correction.

B. Key Scienctific Problems to be solved

The project intends to solve the key scientific issues of aging on cellulose and mineral oil moisture balance between the role of regularity and mechanism Cellulose and mineral oil in water balance between affected by many factors, including the aging factors and mechanism of the law is not clear, from the microscopic parameters required (specific surface area of cellulose, mineral oil interfacial tension), macroscopic properties (such as different effective aging time of cellulose and mineral oil in the water balance value) and other aspects of research, in essence be revealed.

II. CELLULOSE AND WATER BALANCE BETWEEN MINERAL OIL RESEARCH SIGNIFICANCE AND STATUS

Cellulose cardboard with mineral oils are oil-immersed transformer main insulation material, the moisture content of oil-paper insulation increase will severely reduce the mechanical strength and electrical strength, resulting in reduction of insulation life [1]-[4]. Doubling the water content, the insulating paperboard half-life is reduced, heat aging rate doubling [5]. Prevent wet insulation, transformer life extension, convenient and accurate detection of cardboard and oil in the water content is very important. The moisture content in oil coulometric method for detecting the main use, convenience sampling, and technology is more mature. Paperboard moisture content detection methods include dew point method, the electrical measurement and chemical measurements. Dew point method must be power outages, time-consuming and difficult to carry out on-site. Traditional insulation resistance, tan δ and other electrical measurements can be used for qualitative measurement of the moisture content of cardboard. Dielectric response method [6]-[7] in the measured quantity and the relationship between cardboard moisture remains to be studied further. Chemical measurement method is mainly Karl Fischer method, the method can more accurately measure the moisture content of cardboard, but the site is difficult to run the equipment taken to the cardboard sample. The usual practice is to measure the moisture content of the oil, then the oil, the water balance between the paper between the paper sheets to calculate the water [2]-[8].Although the balance between moisture greaseproof paper is affected by temperature, when the temperature changes, the results obtained by this method large error [9].However, the actual load of which can be adjusted, the cooler input methods and other methods, so that the transformer is a relatively stable temperature to reduce

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errors. Oil, paper, water balance between the curves has important practical value. Currently, the available moisture equilibrium curve using greaseproof paper mainly includes Fabre-Pichon curves [10], Oommen curve [2]-[8], Griffin curve [11] and so on. Mit's Y. Du et al test results show that, Oommen curve data is most consistent with the experimental results [12-14]. However, the above curve and the tests were based on a new board with oil, oil and cardboard without considering the aging factor.

III. CELLULOSE AND MINERAL OIL ABSORBENT ABILITY TO INFLUENCE QUALITATIVE ANALYSIS

Moisture in cellulose and mineral oil depends mainly depends on the balance between cellulose and mineral oil absorption capacity is saturated water content. In the equilibrium state, the relative content of water in the cellulose and mineral oil relative moisture content value is the same. Aging whether they would moisture balance between the cellulose and mineral oils impact of aging depends on whether they would cellulose absorbent capacity of mineral oil and impact.

A. Absorption Mechanism of Cellulose

Absorbent fibers mainly through the following ways to complete [15]:

i. The role of the hydrophilic group: The fiber molecule, the number of hydrophilic groups can affect the strength and polarity of the size of its absorption capacity. More number of the hydrophilic group, the polarity, the stronger the higher the fiber absorption capacity. Hydrophilic group and a great affinity for water molecules, with the water molecules to absorb water, the fiber affects the absorption capacity of the main factors. Representative hydrophilic group's include-OH,-COOH-,-CONH- and-NH 2 and Cellulose αhydrophilic groups are hydroxyl (-OH), each containing 2-3 glucose units hydroxyl groups.

ii. The fiber crystallinity: Cellulose is crystalline and amorphous zones formed by connecting two staggered phase system. If lower the crystallinity of the fiber, then has stronger absorption capacity. If the same degree of crystallinity, then smaller the micro-crystals, could increase stronger the absorption capacity. Fiber gap amorphous region more holes bigger, stronger fiber moisture absorption capacity. Cellulose is about 70% of the crystalline portion and 30% amorphous part.

iii. The specific surface area of the fiber: Fibers per unit volume or unit mass of the total surface area is referred to as the specific surface area. The greater the specific surface area of the fiber, the greater the surface energy, surface adsorption capacity is, the number of adsorbed water molecules is also more moisture as possible. The binding force of the lower surface adsorbed water, moisture adsorption and desorption are faster.

The following table shows the corresponding three kinds of methods of moisture adsorbed species and water species and weak binding force.

TABLE-1 METHODS OF MOISTURE ADSORBED SPECIES AND WATER SPECIES AND WEAK BINDING FORCE

Hygroscopic way	Adsorption of water species	The type and strength of the binding force	**1**
Hydrophilic group	Absorption	Word Bond strength, strong	***2***
Crystallinity	Capillary water	Vander Waals force, the weak	3
Specific surface area	Surface adsorbed water	Vander Waals force, the weak	4

The destruction of the cellulose molecule aging mainly through pyrolysis, pyrolysis of glucose monomers insufficient strength of damage, but will result in glycosides bond cleavage, the performance reduction of polymerization degree n. Every time this happens cracking will increase two hydroxyl groups. Degree of polymerization of the new board is about 1200-1500, end of life the polymerization of about 250, that is six times during cleavage, the increase in hydroxyl number of 12,and compared with the original hydroxyl number of about 3000-4000 increased by not more than 0.2%. Visible, cardboard after aging unit volume change in the number of hydroxyl groups is small, it causes a change of the absorption capacity is negligible [16]. The study showed that the aging cause the cellulose crystallinity becomes small, the grain size decreases, and the amorphous region increases the number of holes. This would theoretically lead to enhanced absorbent capacity of aging of cardboard. However, due to the presence of oil, so that oil instead of water is first filled with these holes, forming" capillary oil." Oil in the water in the water than the cardboard lower three orders of magnitude, "capillary oil" on the contribution of cardboard moisture is almost negligible. Therefore oil, paper systems, aging cardboard could a change in the degree of crystallinity changes very little moisture absorption capacity [16]. However, after aging cardboard, the microscopic voids becomes large, the fiber length becomes shorter, the polymerization degree and a decline in tensile strength [17]. It will inevitably affect the surface area of cellulose, thereby affecting the absorbent capacity of the cellulose cardboard.

B. Absorpation Mechanism of Mineral Oil

Mineral oil is a hydrophobic solvent, water molecules and no chemical bonding between the oil molecules. In the form of an emulsion of water in mineral oil, mineral oil and water absorption capacity depends on the interface between the interface tensions; the weaker the absorbent capacity of the mineral oil is stronger. The hydrophilic material in mineral oil and other factors has interfacial tension by the temperature. With the increase of aging, mineral oil acid (hydrophilic substance) is increased, the interface tension decreased [18]-[19], which causes the increase in mineral oil absorption capacity.

In summary, aging on cellulose and mineral oil absorption capacity will have an impact. In addition, the longer operating life in a sealed oil-immersed transformer condition persists significantly increased moisture in oil phenomena caused by the aging of existing theory that cellulose molecules with mineral oil cracking is the main cause of the phenomenon, but cellulose and mineral oil based water balance curve between the water content of the oil is much lower than the added value of the measured data, which would further explain the aging process cellulosic material with mineral oil water balance between impact existing fiber plain water with mineral oil between the equilibrium curve in aging conditions no longer apply.

IV. RESEARCH METHOLOGY

A. The Aging of Cellulose absorpation Capacity Involing microscopic parameters

Aging effects of different cellulose with mineral oil sample preparation method; specific surface area of the sample of the cellulose samples with mineral oil interfacial tension mechanisms involved in the absorbent structure of the microstructure of the measurement method; study the specific surface area and other cellulose efficiency as a function of aging time; study the equivalent mineral oil interfacial tension as a function of aging time

B. Identify the Headings Water in the Equivalent Aging Time Between samples of Cellulose And Mineral Oil Equilibrium curve

Equivalent aging time of different cellulose in combination with mineral oil sample, the relative humidity of the typical moisture and temperature conditions, the cellulose and the balance of the content of mineral oil to create different aging time equivalent mineral oil, a paperboard moisture equilibrium curve; the existing oil, paper, water balance between the different aging conditions curve correction.

C. Figures Cellulose with Mineral oil Vetween The Mathematical Model of the water Balance

Absorption capacity of the cellulose and cellulose as a function of the specific surface area, the equivalent of cellulose absorption capacity as a function of aging time; study of mineral oil absorption capacity and the functional relationship between interfacial tension, research capabilities and mineral oil temperature and moisture a function of aging time equivalent; build cellulose and mineral oil between water balance model.

Research program to be adopted and feasibility analysis

1) Preparation of samples aging

The use of the method of accelerated thermal aging specimen preparation, to be prepared by unaged, the equivalent of 10 years of aging, the equivalent of 20 years of aging, equivalent to 30 years of age and 40 years of aging five kinds of cellulose cardboard equivalent sample and 5 mineral oil samples.

Select the sample

Weidman 0.5mm thick specimen using cellulose medium density cardboard to reduce moisture in cellulose and mineral oil balance between times and improve test efficiency; mineral oil samples using domestic transformer commonly used Karamay 25 # transformer oil, the test more representative.

Aging methods

The dried cellulose cardboard with mineral oil mixed at a ratio of 10:1 into the sealed glassware and emptying the bottle of air with nitrogen, oxygen in the air to avoid the influence of the aging process. To prepare a sample placed in oven at 130 under the conditions of accelerated thermal aging accelerated thermal aging time by controlling the type of the equivalent aging time. Aging time equivalent is calculated according to IEC 354-1991 standard.

The aging of specimen preparation has been adopted by many universities; the applicant preliminary research has also been used to good effect

2) Measurement of microscopic parameters

Measurement of the specific surface area of cellulose

The use of the specific surface area and pore size analyzer (in accordance with GB / T 19587-2004 gas adsorption BET method specific surface area of solid material) Measurement of the specific surface area of cellulose cardboard sample, as necessary, the selection of krypton adsorbed gas. The surface area of the fiber changes is observed by scanning electron microscopy (SEM) as an auxiliary measuring tool. Each fiber sample was tested at least 10 sets of data to eliminate errors of measurement.

Measurement of mineral oil interfacial tension

Using the interfacial tension tester (petroleum products meet GB6541-1986 oil on water Determination of interfacial tension (ring method)) measured 25 # mineral oil interfacial tension. The method is proven mineral oil interfacial tension measuring method has been widely used in the power industry. Each mineral oil samples measuring not less than 10 sets of data, in order to eliminate measurement errors.

3) Water balance method and moisture content measurement

The prepared cellulose cardboard with mineral oil sample is placed in wide-mouth glassware, divided into five groups of water balance test, each group of specimens prepared as follows:

TABLE-2 CELLULOSE CARDBOARD WITH MINERAL OIL SAMPLE IS PLACED IN WIDE-MOUTH GLASSWARE

Ssample No.	Mineral oil	Cellulose cardboard	**Remark**
A	Unaged	Unaged, equivalent to 10 years, 20 years, 30 years and 40 years of an aging	The cardboard are first group of

B	The equivalent of 10 years of aging	Unaged, equivalent to 10 years, 20 years, 30 years and 40 years of an aging	specimens with the corresponding degree of aging of oil into the oil and then repeatedly washed to eliminate oil on cardboard in the original test results. For example: A group of cardboard samples are first unaged oil with repeated washing, while the B group of cardboard samples are first degree with an equivalent of 10 years of aging oil for repeated washing.
C	The equivalent of 20 years of aging	Unaged, equivalent to 10 years, 20 years, 30 years and 40 years of an aging	
D	The equivalent of 30 years of aging	Unaged, equivalent to 10 years, 20 years, 30 years and 40 years of an aging	
E	The equivalent of 40 years of aging	Unaged, equivalent to 10 years, 20 years, 30 years and 40 years of an aging	

The opening of each set of test specimens under the conditions of constant temperature and humidity chamber placed in the constant temperature and humidity oven temperature and moisture equilibrium under the set value. As the air, mineral oil and cellulose cardboard balance between the relative humidity to follow the same principles, by controlling the relative humidity of the air temperature and humidity box can control the water balance of the cellulose and mineral oil after the relative humidity, and then measured their absolute moisture content. Because water is the cellulose and mineral oil is also affected by the temperature equilibrium, and therefore need to be balanced at different temperatures.

Typical temperature setting is 20 , 40 , 60 and 80 , the typical humidity set value of 20%, 40%, 60% and 80%, a total of 16 combinations.

Process can be periodically measured water balance water in oil, water in oil content tends to be stable, indicating that equilibrium has been completed, and then measured by Karl Fischer moisture in the cellulose cardboard. Because low temperatures slow the migration of moisture, balance takes longer, this work is time-consuming.

Such applicant's water balance method has been used in previous related research, testing to good effect.

4) Construction of cellulose and mineral oil water balance model

Cellulose cardboard equivalent aging time and the corresponding data fitting than the surface area, the establishment of the specific surface area of cellulose cardboard and the equivalent function of aging time; cellulose cardboard according to moisture equilibrium relative water content and water content calculated absolute The saturation water content of cellulose cardboard, cardboard cellulose aging time and the corresponding equivalent data fitting saturated water content, water content and create the equivalent of cellulose cardboard saturation function of the aging time; the equivalent mineral oil aging and its corresponding time data fitting the interfacial tension, the surface tension of mineral oil to establish the equivalent function of the aging time; moisture equilibrium under the relative water content of mineral oil and mineral oil content calculation absolute saturation water content, the mineral oil The equivalent aging time and the corresponding data fitting saturated water content, water content and create the equivalent mineral oil saturation function of the aging time. According these four functions, we could the eventual establishment of cellulose with mineral oil to build water balance model.

CONCLUSION

The cellulose and mineral oil are two chiefly components which used as insulation material in power transformer. In conclusion, the specific surface area of the cellulose sample and the interfacial tension of the mineral oil sample have been measured. The moisture in cellulose and mineral oil are measured at various temperature and humidity condition. The mathematical model of moisture equilibrium of cellulose and mineral are presented and the moisture equilibrium curves were corrected in aging condition

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