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열적열화된 변압기용 절연유의 유전특성 분석

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Dielectric Characteristic Analysis of Thermally Aged Insulating Oil for Transformers

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Abstract - The purpose of this paper is to provide the fundamental data which can be used for the design of pole transformers. For the purpose, electrical characteristics of aged mineral oil and silicone oil were analyzed by comparing with the results of virgin ones.

For the experiment, an oil bath which can keep constant temperature was constructed to thermally deteriorate the specimens. And transformer materials were put together in the bath according to the their ratio in weight in the pole transformer. And the parameters such as relative permittivety, $\tan\delta$ and specific resistance were measured.

As a results, the permittivity of silicone oil was higher than that of mineral oil, and its decreasing rate with temperature was also higher. In addition, it was found that $\tan\delta$ and specific resistance of virgin and aged oil began to differ at similar temperature.

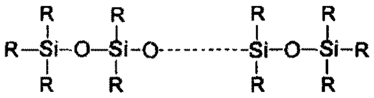
1. Introduction

Various characteristics of the insulating oil employed in oil transformers was improved by many scholars. However, most generally used one is still mineral oil, and silicone oil is partially adopted by the application of the transformers. Since the theorematical and experimental works were introduced in lots of documents[1], only silicone oil is theoretically explained in section 2 of this paper.

2. Silicone

Silicone has been academically studied and industrially developed by lots of scholars since Swedish J.J Berzelius first composed silicone chloride by separating silicone. Nowadays, silicone is widely employed from cutting edge technology to our common life because of its unique characteristics and effectiveness.

Silicone is a high performance material and has both organic and inorganic nature, therefore it is indispensible for most industrial fields. It is composed of polymers chemically combined by silicon containing organic component and oxygen. Chemically, silicon is a concept strictly distinguished from silicone, the former means metallic dark gray silicon represented by Si and mainly adopted as semiconductors or organic silicone such as latter by processing. In case of latter one, it can be divided into 3 groups; oil; rubber; resin. They are uniquely related one another and Fig.1 shows the molecular structure of silicone oil among them.



$$R-\overset{R}{\underset{R}{Si}}-O-\overset{R}{\underset{R}{Si}}-O\cdots\cdots\cdots\overset{R}{\underset{R}{Si}}-O-\overset{R}{\underset{R}{Si}}-R$$

Fig.1 Molecular structure of silicone oil

As shown in Fig.1, silicone oil has a chain shaped molecular structure. The skeleton of this molecular is composed of syloxane bond and individual molecular exists independently. Therefore, the molecular chains freely move, which makes the silicone molecular fluid. However, the longer the molecular length is, the higher the viscosity of silicone is, so desired viscosity can be acquired by controlling the polymeric degree.

The well known chemical properties of silicone oil are; it is strongly withstand against thermal stress and oxidation. Since electronegativity between silicon and oxygen is high, it is close to ionic bond, which makes it very stable in energy. Therefore, it can be used even in high temperature; The bond between silicon and oxygen is ionic bond, however silicon is weak for hydrolysis. Therefore, when there is a catalyst to hydrolyttic reaction, silicon molecular becomes low molecular weight, which makes it weaken.

By the way, the physical properties of silicone oil are; attractive force between moleculars is weak, so the free energy of the surface is low, which makes it spread out on the surface of an object; it is very effective to industrialize compared with the other materials since its freezing temperature is very low; it is hardly affected by temperature because the distance between moleculars is long. Nowadays, the most widely used one is dimethyl-silicone oil.

3. Experimental

3.1 Experimental setup

For accelerative ageing of mineral oil(class 1, No.2) and silicone oil under the similar environment to the real transformer condition, the insulating oil was mixed with the transformer materials according to the material component ratio of real transformers shown in Table 1, and an oil bath for accelerative ageing of the mixed materials was constructed as shown in Fig.1.

Table 1 Component ratio of materials used in transformer

component	core	oil	coil	paper	etc.
ratio[%]	51.6	28.6	17.4	2.3	0.1

※core : silicon steel coated by MgO
oil : mineral oil(class 1, No.2) and silicone oil
coil : copper wire coated by enamel
paper : 0.18㎜ thick kraft paper, diamond dotted paper, Nomex paper
1.8㎜ thick pressboard

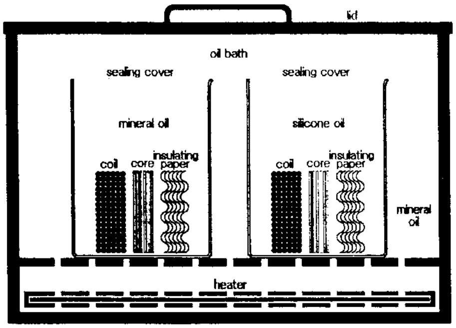


Fig.2 Oil bath for accelerated ageing of specimen

As shown in Fig.2, the transformer materials were deteriorated, by a double boiling method, at 125℃ which is the temperature over the transformer operating temperature and below the boiling temperature of the mineral oil.

3.2 Experimental procedure

To measure the dielectric values and specific resistance of the virgin and thermally aged insulating oil, they were installed in sample cell. The capacity of the samples have to keep specified value to get more exact results, for this reason, golden circular electrodes(35㎜ in diameter) was used and the distance between the two electrodes was strictly kept to 0.5㎜ in this experiment. Fig.3 shows the schematic of the specimen installed in sample cell.

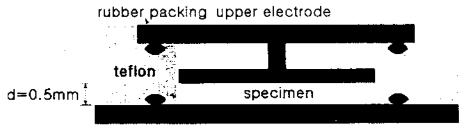


Fig.3 Schematic of the specimen installed in sample cell

The specimens were divided into the aged group and the virgin comparison group to compare the results of the aged one, and temperature and frequency were taken as the experimental variables to the virgin specimen and the deteriorated specimen. Temperature was increased from -20℃ to 80℃ at every thermal step of 2℃. The permittivity, the tan δ and the specific resistance to each frequency were measured at each temperature with error bound of ±0.5℃ and only their typical values were shown in this paper.

4. Results and discussion

The results of the measured permittivity of the virgin and aged mineral oil are shown in Fig.4.

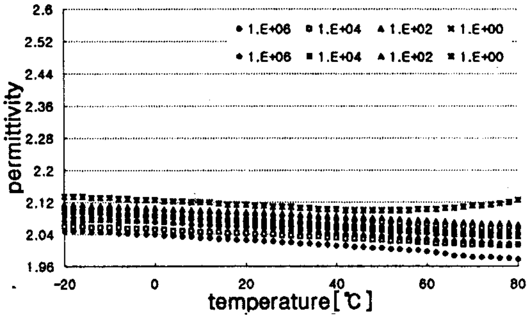


Fig.4 Permittivity comparison of aged mineral oil with virgin mineral oil(hollow:virgin, filled:aged)

As shown in Fig.4, most permittivities of virgin and aged mineral oil were slightly decreased with temperature. However, only the permittivity of the aged mineral oil began to be increased just passing around 55℃. And the permittivity of the aged mineral oil was somewhat increased compared with the permittivity of the virgin mineral oil.

The tan δ of the virgin and aged mineral oil is shown in Fig.5.

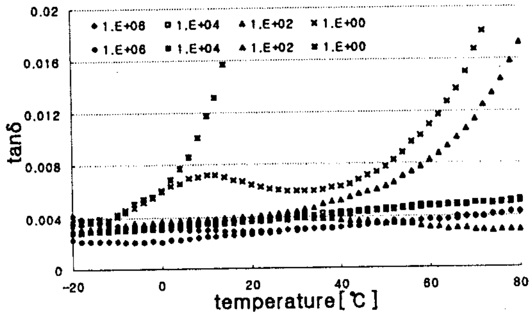


Fig.5 tan δ comparison of aged mineral oil with virgin mineral oil(hollow:virgin, filled:aged)

As shown in Fig.5, tan δ of the virgin and aged mineral oil was mostly similar each other at frequency equal or more than 10^4Hz, the tan δ difference was increased at low frequency. In particular, tan δ of the aged mineral oil tended to be much more increased than that of the virgin mineral oil from 22℃ at 10^2Hz and 0℃ at 10^0Hz.

The specific resistance of the virgin and aged mineral oil is shown in Fig.6.

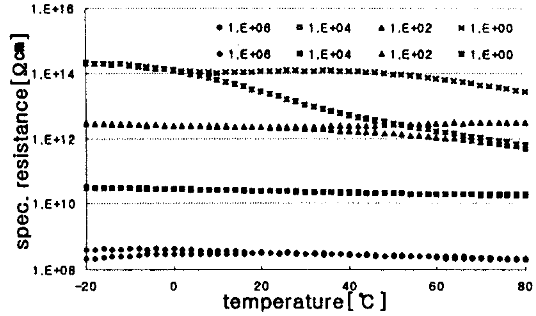


Fig.6 Specific resistance comparison of aged mineral oil with virgin mineral oil(hollow:virgin, filled:aged)

As shown in Fig.6, the specific resistance of the virgin mineral oil was almost similar to that of the aged mineral oil at high frequency, however the lower the frequency was, the higher the tanδ difference between the virgin mineral oil and the aged mineral oil. Furthermore, the temperature where the difference of the specific resistance began to occur was almost same as the temperature where the difference of the tanδ began to occur.

The permittivity comparison of aged silicone oil with virgin silicone oil is shown in Fig.7.

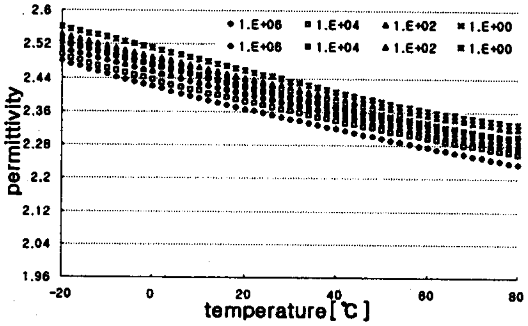


Fig.7 Permittivity comparison of aged silicone oil with virgin silicone oil(hollow:virgin, filled:aged)

As shown in Fig.7, the permittivity of the virgin and aged silicone oil was linearly decreased like that of mineral oil, but the permittivity decreasing rate of silicone oil was higher than that of mineral oil. In addition, the permittivity of silicone oil was increased compared with that of mineral oil and the permittivity of the aged silicone oil was slightly higher than that of the virgin silicone oil.

Fig.8 shows the tanδ of the virgin and aged silicone oil.

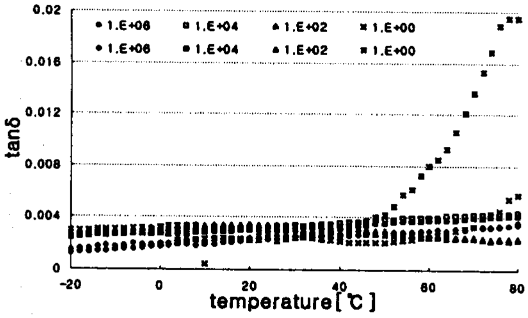


Fig.8 tanδ comparison of aged silicone oil with virgin silicone oil(hollow:virgin, filled:aged)

As shown in Fig.8, tanδ of the virgin silicone oil began to differ from that of the aged silicone oil in the temperature range over 35℃ at 10^0Hz and tanδ at other frequencies was almost similar one another.

The specific resistance comparison of aged silicone oil with virgin silicone oil is shown in Fig.9.

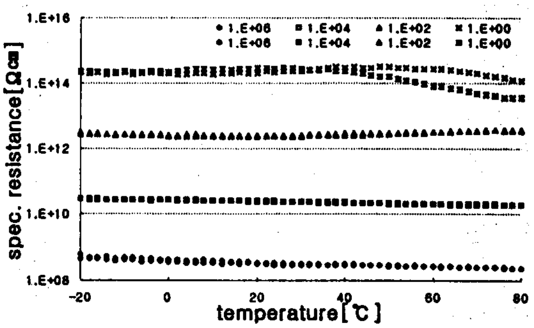


Fig.9 Specific resistance comparison of aged silicone oil with virgin silicone oil(hollow:virgin, filled:aged)

As shown in Fig.9, the specific resistance of silicone oil was decreased with frequency. Particularly, the specific resistance difference between the virgin silicone oil and the aged silicone oil began to occur from the temperature over 35℃ at only 10^0Hz. And the specific resistance at other frequencies was almost similar in both the virgin and aged silicone oil. In addition, similarly to the case of mineral oil, the temperature where the difference of the specific resistance began to occur was almost same as the temperature where the difference of the tanδ began to occur.

5. Conclusions

In this paper, the dielectric characteristics and specific resistance of the transformer insulating oil subjected to accelerative ageing was treated by comparing with those of the virgin's. As a result, this paper concludes as follows;

(1) In case of the permittivity, silicone oil had higher values than mineral oil, and the permittivity of both insulating oil was linearly decreased with temperature. And the permittivity decreasing rate of silicone oil was higher than that of mineral oil.

(2) The tanδ of both insulating oil was generally proportional to temperature but reciprocal to frequency. Furthermore, tanδ difference began to occur at equal or less than 10^2Hz in case of mineral oil and at 10^0Hz in case of silicone oil.

(3) The specific resistance of the virgin and aged oil was reciprocal to frequency. But for low frequency, it kept almost constant value in temperature range of -20℃~80℃. The specific resistance difference between the virgin and aged oil began to occur at frequency equal or less than 10^2Hz in mineral oil and at 10^0Hz in silicone oil. The temperature where the difference of the specific resistance began to occur was almost same as the temperature where the difference of the tanδ began to occur.

[References]

[1] H. Asai et al., Electrical Insulating Oil Handbook, Japan Petroleum Institute, 1987. 2.