Physical and Electrical Characteristics of Varnish and Varnish Treated Insulating Paper for Pole Transformers

Jong-Wook Jung*, Il-Keun Song*, Kyo-Sun Koo, Hyun-Seok Song**, Hee-Ro Kwak** and Yong-Huei Han***

Abstract - This paper describes the mechanical and electrical characteristics of insulating paper impregnated with diluted varnish(W-128), according to Korean Standards. The varnish was diluted with a solvent of 6 different wt%. Kraft paper and Nomex paper were impregnated with the diluted varnish in a vacuum condition, and then completely dried. As the mechanical characteristics, the thickness of the completely dried varnish, the drying time and the tensile strength of the specimens were measured, and as the electrical characteristics, the permittivity, the tan δ and the specific resistance were evaluated as well.

Keywords : mechanical and electrical characteristics, insulating paper, varnish, permittivity, tan δ, specific resistance

1. Introduction

A pole transformer in power systems is one piece of electrical equipment installed closest to customers. It negatively affects customers when it encounters a fault. Therefore, its importance in the distribution system cannot be emphasized too much since the reliability in power supply strongly depends on it. As many researchers have investigated it since it was invented, it has been remarkably improved in performance. However, considering the results of KEPRI's testing of the distribution transformers from 1995 to 1999, about 30[%] of the disqualified transformers were too weak to withstand the test requirements, despite the improvement in quality[1]. When the pole transformer reaches a short circuit fault due to a breakdown in insulation between layers, the conductors are deformed or broken by hoop and buckling stresses in severe cases. Therefore, after winding the conductors, the conductor and insulating paper/pressboard assembly is impregnated with varnish in a vacuum condition and completely dried, or the conductors are bound together with diamond dotted paper on which adhesive epoxy resin is coated to raise the short circuit withstand strength of the pole transformer. Especially, most domestic manufacturers employ the diamond dotted paper together with the varnish impregnating method, but foreign companies wind the coils on Nomex paper or diamond dotted paper only, which improves the short circuit withstand strength of the pole transformer. However, the varnish is a distinct material from the insulating paper, and performs its real ability after complete varnish impregnating and drying treatments, which depends on the treating condition and the properties of the impregnated materials as well as the properties of the varnish[1][2]. In other words, there can be unexpected problems in insulation when the insulating paper is impregnated with the varnish, which may cause a side effect against the original purpose of improving the short circuit withstand strength. When considering the fault causes, practical studies on the varnish are not enough yet even though most of them were due to improper varnish treatment.

Therefore, to utilize the acquired results as practical data in designing and manufacturing the pole transformers, the mechanical and electrical characteristics of the insulating paper for pole transformers were measured after impregnating the insulating paper with varnish diluted with solvent.

2. Experimental setup and procedure

The varnish impregnated insulating paper was assessed mechanically and electrically.

2.1 Mechanical tests

2.1.1 Drying test

To measure the time to complete the drying of 6 varnish specimens with different concentrations, they were left at room temperature according to Korean Standards[3]. The varnish was diluted with solvent and the content ratios of

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varnish were 30, 40, 50, 60, 70 and 100[wt%]. After blending the varnish with the solvent, it was pretreated in a vacuum desiccator for 3 hours to eliminate the bubbles in the specimens. 50[cc] of the prepared specimen was dripped on the clean glass plate(1[m] long) and the glass plate was erected vertically to the ground, so that the varnish could freely drip. And then, the time to the bottom of the glass plate, the complete drying time and the thickness of the varnish after complete drying were measured. The laboratory temperature was 23[℃], and humidity was 65[%].

2.1.2 Mechanical strength tests

a. Adhesive strength test

Specimens were prepared to measure the adhesive strength of the diluted varnish according to Korean Standards, as shown in Fig. 1.

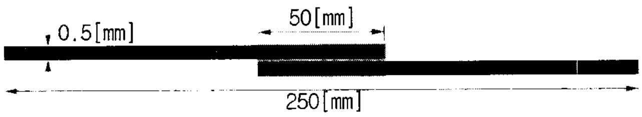


Fig. 1 Specimen for adhesive strength test of varnish

As shown in Fig. 1, 0.5[mm] thick pressboard was sheared by 15×150[mm] to measure the adhesive strength of the varnish, and dried for 1 hour in an oven kept at 60[℃]. This specimen pressboard was soaked by 50[mm] in the 6 diluted varnishes prepared in section 2.1.1, and then 2 sheets of the pressboard were stuck together by pressing them with 500[g] weight, and then naturally dried for 11 hours in the oven kept at 130[℃]. 5 pairs of the specimen were prepared by the wt% of the varnish. The specimen was installed between 2 legs of the tensile strength tester(INSTRON model 4204), and then stretched by 20[mm/min]. The load was measured when the specimen was completely separated.

b. Tensile strength test

Stretching the specimen paper at a speed of 50[mm/min], the load was measured when the specimen was completely cut off, to evaluate the tensile strength before and after the varnish-impregnation of the paper. The tensile strength was calculated by dividing the cut load[kg] by the area[mm²] of the cross section of the specimen. An average of 5 experimental results were taken as the tensile strength.

2.2 Electrical tests

2.2.1 Dielectric test

A WinDETA system was used to evaluate the dielectric characteristics of the insulating paper treated with the diluted varnish, and Fig. 2 shows the schematic of the system.

As shown in Fig. 2, the insulating paper dried at 110[℃] for 11 hours after the varnish treatment in a vacuum condition was placed between 2 electrodes. Frequency was selected as a parameter, and the permittivity, the tanδ and the specific resistance were measured by scanning the frequency. Specimen cell temperature was kept at 23[℃].

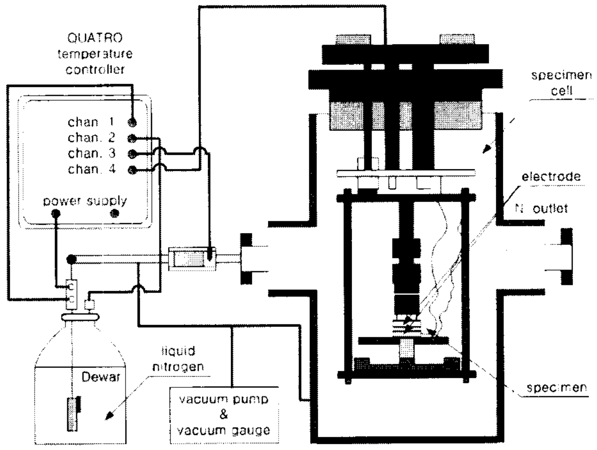


Fig. 2 WinDETA system for dielectric test

2.2.2 Electrical strength test

An experimental arrangement to measure the breakdown voltage of the insulating paper impregnated with the diluted varnish is shown in Fig. 3.

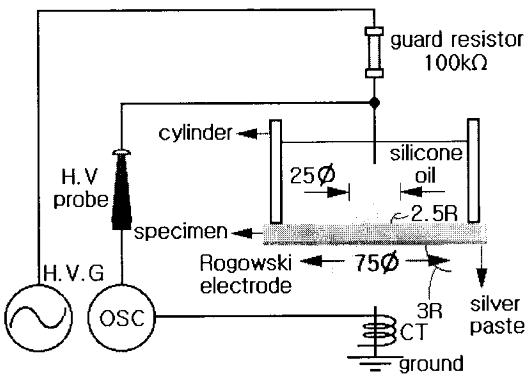


Fig. 3 Schematic of experimental arrangement

As shown in Fig. 3, to measure the electrical strength, each specimen was sheared by 100[mm] in diameter, and it was stuck on the bottom of the transparent short cylinder. The bottom surface of the specimen paper was painted with silver paste. This specimen set was arranged on the lower plain stainless Rogowski electrode. The upper plain stainless Rogowski electrode(about 600[g]) of 25[mm] in diameter and edge-rounded by 2.5[mm] in radius was put on the specimen paper. Then the upper electrode was impregnated with silicone oil and connected to a high voltage generator(H.V.G), and the lower electrode was grounded. The 100[kΩ] guard resistor was inserted in a series into the specimen in order to protect the H.V.G from the impulse current and voltage at the breakdown of the specimen. A high voltage probe(1,000:1) was installed parallel to the specimen in order to measure the applied voltage. As the applied voltage was increased at the rate of 3[kV/s], the breakdown voltage was measured 10 times.

After the measurement, the maximum, minimum and average values were calculated.

3. Results and discussion

3.1 Mechanical characteristics

3.1.1 Falling speed, drying time and thickness of diluted varnish

Among the mechanical characteristics of the varnish, the time to the bottom of the glass plate and the drying time are shown in Fig. 4, and the thickness of the varnish after complete drying is shown in Fig. 5.

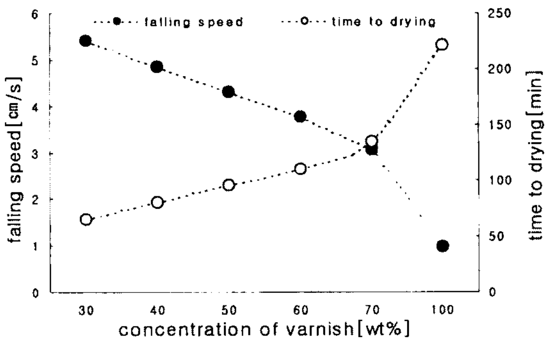


Fig. 4 Falling speed and drying time of diluted varnish

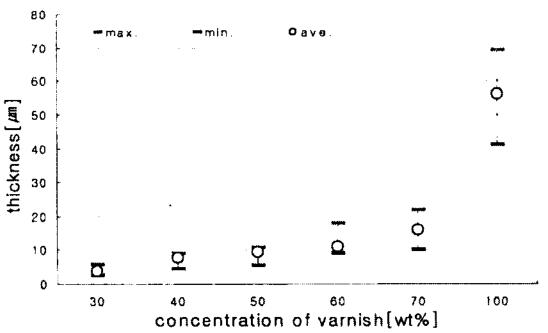


Fig. 5 Thickness of diluted varnish after complete drying

As shown in Fig. 4, the falling speed of the diluted varnish decreased with the varnish concentration. The complete drying time of the varnish according to Korean Standards took longer with the varnish concentration. This is considered because the viscosity and the volatility of the varnish/solvent mixture is proportional to the varnish concentration. In addition, because of the surface tension and the viscosity, the diluted varnish thickened with the varnish concentration, as shown in Fig. 5.

3.1.2 Tensile strength of insulating paper treated with diluted varnish

The adhesive strength of the diluted varnish and the tensile strength of the varnish treated insulating papers were measured according to Korean Standards. Fig. 6 and Fig. 7 show the results, respectively.

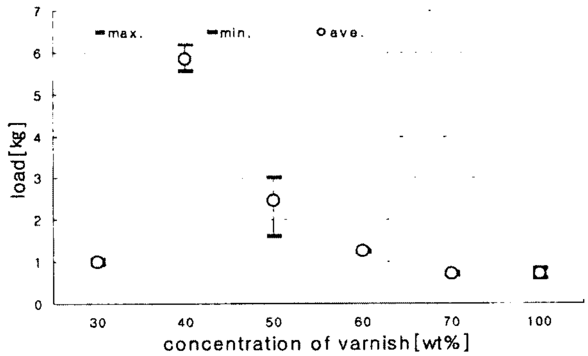


Fig. 6 Adhesive strength of diluted varnish

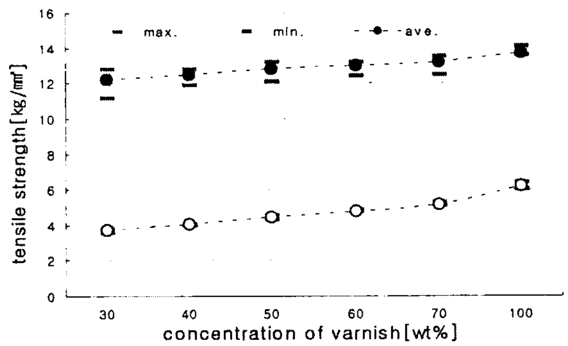


Fig. 7 Tensile strength of varnish treated insulating papers (hollow : Kraft paper, solid : Nomex paper)

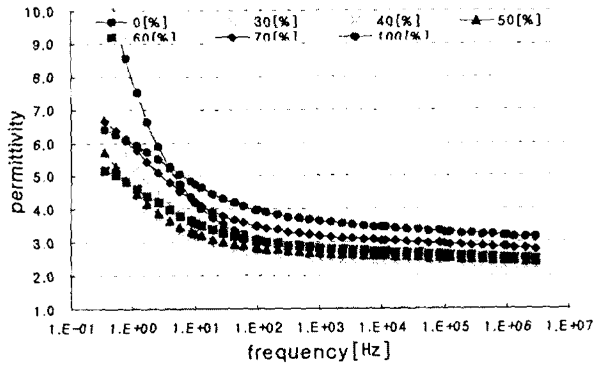
As shown in Fig. 6, the varnish could withstand the maximum load when the varnish concentration was at 40[wt%]. As the varnish concentration increased, the stuck part of the specimen was separated by slipping off. As also shown in Fig. 7, Nomex paper was about 3 times stronger than Kraft paper in tensile strength, and the strength slightly increased with the varnish concentration. This is considered because the varnish content with adhesive power combines with the fiber of the insulating paper.

3.2 Electrical characteristics

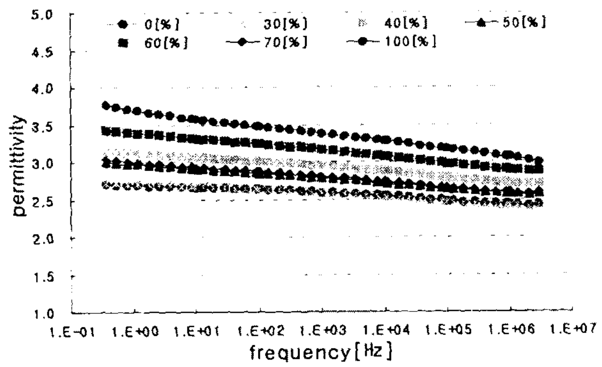
3.2.1 Dielectric test

The permittivity of the varnish treated insulating papers was measured, and Fig. 8 shows the result.

As shown in Fig. 8, the permittivity of the insulating papers decreased with frequency, especially that of Kraft paper exponentially dropped below 10^2[Hz]. The permittivity of Kraft paper was varied from 2.3 to 3.2 at 23[℃], 10^6[Hz], and it had a minimum value at 40[wt%] of the varnish concentration, which complied with the result acquired from the adhesive test of the varnish. However, considering the global decreasing trend of the insulating papers, it was more stable in Nomex paper because its deviation was not large.

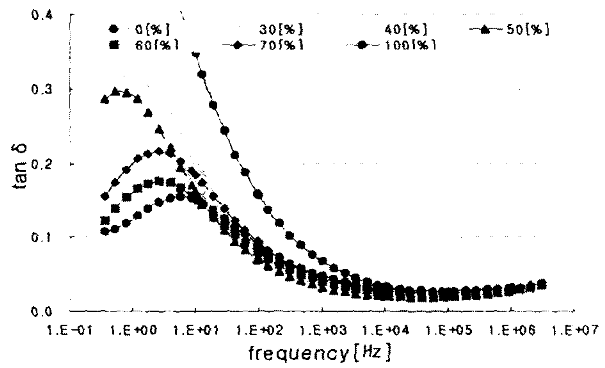


(a) Kraft paper

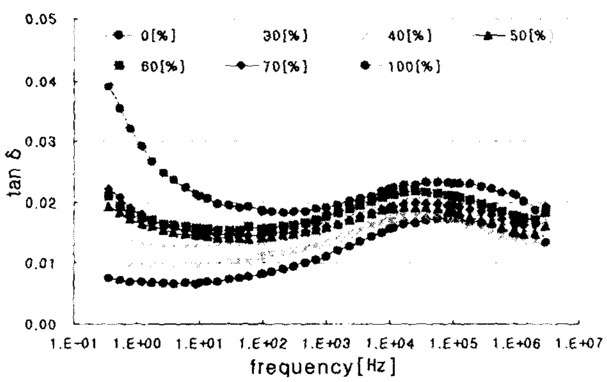


(b) Nomex paper

Fig. 8 Permittivity of insulating paper with frequency



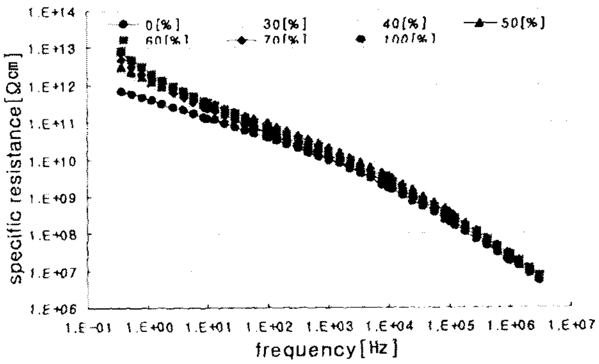
(a) Kraft paper



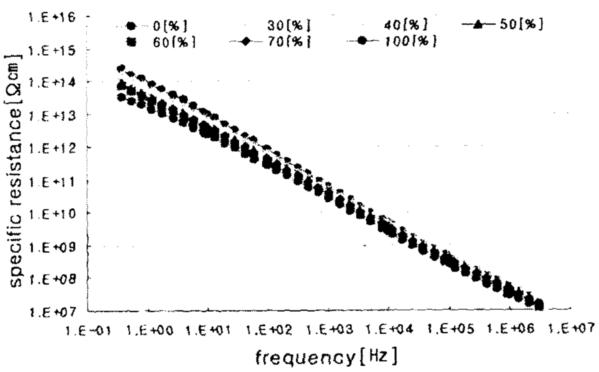
(b) Nomex paper

Fig. 9 tanδ of insulating paper with frequency

As shown in Fig. 9, the tanδ of Kraft paper was significantly varied in the lower frequency range, while that of Nomex paper was barely varied with frequency. Kraft paper was almost 10 times Nomex paper in tanδ. In addition, the tanδ of Kraft paper decreased with the varnish concentration in the very low frequency range below 10^1 [Hz]. On the contrary, the tanδ of Nomex paper increased with the varnish concentration.



(a) Kraft paper



(b) Nomex paper

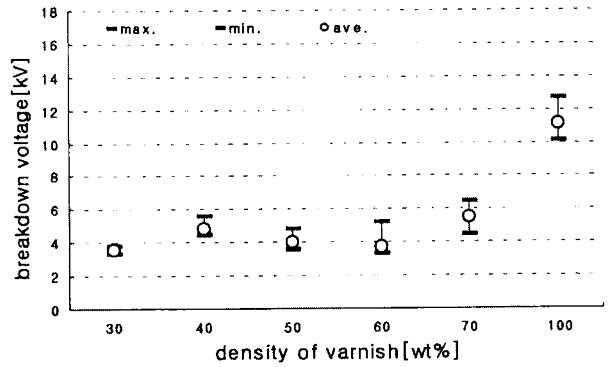
Fig. 10 Specific resistance of insulating paper with frequency

As shown in Fig. 10, the specific resistance of the insulating papers decreased with frequency, and it was confirmed that Nomex paper was more excellent than Kraft paper in dielectric characteristics. In the case of Kraft paper, the specific resistance increased by the impregnation with the varnish, while the varnish impregnation of Nomex paper resulted in the decrease in specific resistance. It is considered that the Nomex paper barely harmonizes with the varnish. To verify the phenomenon more clearly, a breakdown test was carried out, and the results were presented below.

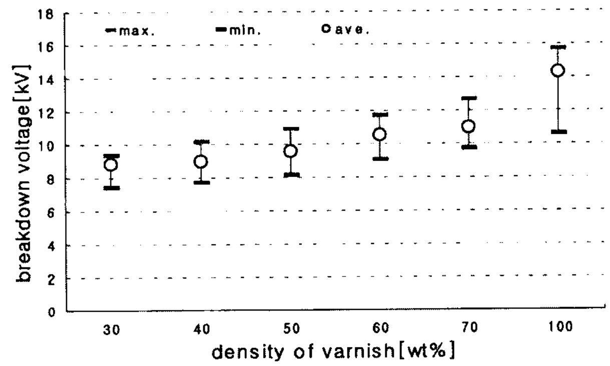
3.2.2 Dielectric strength test

The dielectric strength of Kraft paper treated with the diluted varnish was measured, and Fig. 11 shows the result.

As shown in Fig. 11(a), the dielectric strength of the varnish treated Kraft paper was the highest when the varnish concentration was 100[wt%], while almost similar in other varnish concentrations. The dielectric strength at 40[wt%] was higher than 50[wt%] and 60[wt%]. By the way, as shown in Fig. 11(b), the dielectric strength of Nomex paper increased with the varnish concentration. In the same concentration of the varnish, the dielectric strength of Nomex paper was more than double that of Kraft paper.



(a) Kraft paper



(b) Nomex paper

Fig. 11 Dielectric strength of paper impregnated with varnish

4. Conclusions

The mechanical and electrical characteristics of diluted varnish and insulating paper treated with the diluted varnish were measured in this study. The conclusions are as follows ;

(1) The falling speed of the diluted varnish decreased with the varnish concentration, and the complete drying time of the varnish took longer with the varnish concentration. In addition, the diluted varnish thickened with the varnish concentration.

(2) The varnish withstood the maximum load when the varnish concentration was at 40[wt%]. In addition, Nomex paper was stronger than Kraft paper in tensile strength, and the strength was slightly stronger with the varnish concentration.

(3) In the permittivity, Kraft paper varied from 2.3 to 3.2, and Nomex paper from 2.4 to 3.0 at 23[℃], 10^6 [Hz]. It decreased with frequency, and the global varying trend of Nomex paper was more stable than that of Kraft paper.

(4) Kraft paper was almost 10 times Nomex paper in tan δ. In addition, the tanδ of Kraft paper decreased with the varnish concentration in the very low frequency range below 10^1[Hz]. On the contrary, the tanδ of Nomex paper increased with the varnish concentration.

(5) The specific resistance of the insulating paper decreased with frequency, and it was confirmed that Nomex paper was generally more excellent than Kraft paper in physical and electrical characteristics.

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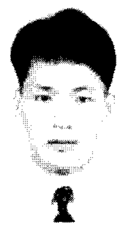

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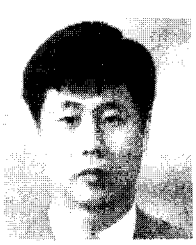

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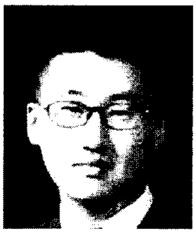

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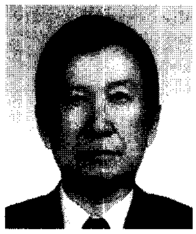

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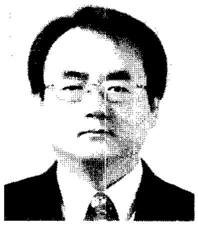

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