

# Research on The Dielectric Property of Nano-doped Aramid Paper

Xinwei Zhang, Xia Zhang, Fangcheng Lyu

North China Electric Power University, China  
Hebei Provincial Key Laboratory of Power Transmission Equipment Security Defense, China

**Abstract:** Oil-paper insulation systems are widely used in high-voltage equipment. Reducing the dielectric constant of insulating paper can improve the dielectric coordination of the oil-paper combination system. At present, a large number of new synthetic insulation materials have been produced, and some new composite insulation papers have low dielectric constant and high electrical strength properties. This article studied the optimal process flow for preparing aramid paper in the laboratory, trial-produced laboratory hand sheets with three types of nanofillers at different doping concentrations, and conducted relative dielectric constant and dielectric loss tests to select Laboratory samples with the best performance; the main research results achieved in the paper are as follows: ①Researched and determined the optimal process flow for making aramid paper in the laboratory, explored the effects of different rolling pressures and rolling temperatures on the dielectric properties of the paper, and determined the optimal rolling temperature and temperature of meta-aramid paper. The pressures are 200°C and 0.3Mpa respectively. ②Meta-aramid paper doped with SiO<sub>2</sub>, TiO<sub>2</sub> and x nanoparticles was prepared, and the relative dielectric properties of the three nanoparticles at the optimal doping amounts (15%, 3% and 4%, respectively) were compared. Constant and dielectric loss, it is determined that the dielectric properties of 4% C<sub>3</sub>N<sub>4</sub> nanoparticle-doped paper are at a relatively excellent level. Compared with pure paper, its relative dielectric constant is not much different, and it can better cooperate with transformer oil. At the same time The dielectric loss is reduced, so nanoparticles of this type and concentration are used as fillers to improve the electrical properties of aramid paper.

**Keywords:** Aramid paper, Nanodoping, Oil paper insulation.

## 1. Introduction

### 1.1. Background of the topic and purpose and significance of the research

Oil-immersed power transformers are mainly used for power transmission and distribution and are one of the most critical devices that determine the safe operation of the power grid. During the operation of the transformer, the performance of the oil-paper insulation system often directly determines the operational safety and reliability of the bushing or even the entire oil-immersed power transformer. During application, the dielectric constant matching problem between mineral oil and cellulose insulating paper will significantly reduce the insulation performance of oil-immersed transformer bushings and affect the operational reliability of power equipment. In recent years, products such as composite insulating paper made of artificial synthetic materials doped in traditional cellulose paper have come out one after another. The problem of dielectric constant mismatch between the two is solved by modifying the insulating paper.

Meta-aramid paper is considered an ideal insulating material in oil-paper systems due to its excellent insulation properties and mechanical strength. Its dielectric constant is usually between 2.2-3.0, so it has better dielectric coordination with mineral oil. However, aramid paper The dielectric loss is higher than that of cellulose paper, Therefore, it has important engineering value and theoretical significance to use nanofillers with excellent screening results to modify and produce aramid-modified paper in laboratories to seek higher electrical properties.

The extremely high global market share of DuPont in the

United States has caused my country's high-end aramid materials to always be controlled by others., Greatly restricts our country's national defense, The development speed of aviation engineering. Nano-doping modified aramid paper improves its dielectric properties, This allows it to be used in oil-immersed transformers and oil-immersed bushings, Invest in a wider range of application scenarios and higher voltage levels, Conducive to improving the performance of domestic aramid paper, At the same time, it will also help to make up for the shortcomings in the performance of domestic aramid paper and the limitations of its application in the electrical field, and achieve overtaking in the development, production and utilization of domestic aramid paper. At the same time, it can also fill the huge gap in the domestic high-performance aramid paper market for electrical applications and break the technical blockade of foreign countries., In order to promote the common development of the domestic aramid paper market and the domestic real economy, it can solve the current bottleneck problem of domestic high-performance materials.

### 1.2. Research on methods to improve the insulation performance of aramid insulating paper

Read the literature to learn, Doping inorganic nanoparticles into aramid paper can reduce dielectric loss. A small amount of nanodoping can significantly improve certain properties of aramid paper, including resistivity, dielectric constant and dielectric loss, breakdown field strength, and other dielectric properties as well as mechanical properties such as tensile strength, hardness, and impact strength. . Insulating inorganic fillers are evenly dispersed in the polymer at the nanometer scale, It has a large specific surface area, high surface activity and some strange physical and chemical effects, which can

block charges and reduce the degree of surface polarization to achieve the effect of reducing dielectric loss. It also increases the polar base through fillers. The resistance of the group or chain segment to follow the polarization orientation of the electric field reduces the dielectric loss. In recent years, scholars such as Zhang Song and Tang Chao have studied nano- $\text{Al}_2\text{O}_3$  doping and  $\text{SiO}_2$  nanoparticle doping and modification, which can effectively reduce the free volume and improve the insulation performance of modified aramid paper to a certain extent.

### 1.3. The main content of this study

In view of the shortcomings of existing research, this article studies the optimal process flow for preparing aramid paper in the laboratory and Trial-produced laboratory hand sheets of three types of nanofillers with different doping concentrations, and conducted electrical performance tests to discover the optimal concentration of each filler. Lateral comparison of the optimal concentrations of different nanofillers Relative permittivity and dielectric loss, choose out dielectric Laboratory samples for optimal performance.

## 2. Nano-modified aramid paper preparation and performance studies

This chapter studies the paper-making process of meta-aramid paper under laboratory conditions, and determines the optimal paper-making process of meta-aramid paper based on the dielectric properties. On this basis, the manufacturing of composite aramid insulating paper was completed.

Based on the literature review, three nanofillers with good thermal conductivity were selected:  $\text{SiO}_2$ ,  $\text{TiO}_2$ , and  $\text{C}_3\text{N}_4$ . The dielectric properties of the three composite insulating papers at different doping amounts were compared, and the optimal doping amounts of the three fillers were determined. The relative dielectric constant and dielectric loss of composite paper and ordinary aramid paper were compared under the optimal doping amount, and the composite paper- $\text{C}_3\text{N}_4$  composite aramid insulating paper with improved performance was selected.

### 2.1. Aramid paper manufacturing process

#### 2.1.1. Ordinary aramid paper manufacturing process

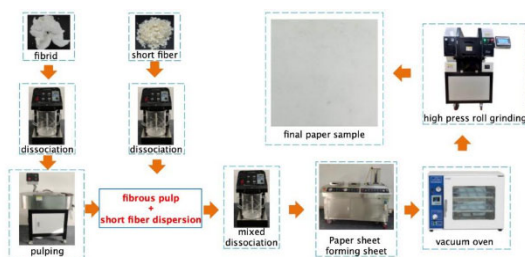


Figure 1. Flow chart of ordinary aramid paper manufacturing

##### 2.1.1.1 Fiber beating treatment and chopped fiber dispersion treatment

The capacity of the fiber beater used in the laboratory is 23 liters. Select the concentration of the fibril pulp to be three thousandths, and calculate and weigh the fibrils. First, the fibrils are dissociated, and the dissociated fibrils are loosened for 10 minutes, and then beaten for 30 minutes.

According to the fiber ratio of different papers, weigh the

chopped fibers, add water and an appropriate amount of dispersant, dissociate for 10,000 revolutions, then add the fibril slurry, dissociate for 20,000 revolutions to mix the two evenly, and adjust the pH of the mixed slurry Adjust the value to the appropriate range.

##### 2.1.1.2 Paper sheet forming

Add the fiber mixed slurry prepared above into the paper sheet forming machine, add water to the mark of 9L, stir quickly until the fibers are evenly dispersed, click the quick drainage and vacuum dehydration buttons in sequence, and fix the filtered aramid paper with a forming cloth, 100 Dry under vacuum at  $^{\circ}\text{C}$  for 16 minutes. In order to prevent the forming cloth from adhering to the paper, it should be turned over several times.

##### 2.1.1.3 Preheating and rolling treatment

During the test, it was found that aramid paper would bubble when the rolling temperature exceeded  $120^{\circ}\text{C}$ ; after preheating for one minute, the aramid paper no longer blistered, and the paper was relatively smooth. Therefore, the prepared aramid paper should be preheated in a vacuum drying oven for one minute, and the preheating temperature and rolling temperature should be the same.

The preheated paper is rolled, the appropriate temperature and rolling pressure are set, and the paper is rolled once in each of the four directions.

#### 2.1.2. Effect of high-temperature rolling on the paper-making properties of meta-aramid paper

After vacuum extraction, the initially formed aramid paper is drier, has a looser structure, poorer tightness, and poorer electrical properties. High-temperature rolling will greatly reduce the thickness of aramid paper, making the paper surface smooth and flat. The mechanical and dielectric properties of aramid paper will be significantly improved after rolling treatment. As a key process in the processing of aramid paper, high-temperature rolling directly determines the performance of the paper. Therefore, it is necessary to study the impact of the rolling process on the performance of meta-aramid paper.

##### 2.1.2.1 Effect of rolling pressure on dielectric properties of aramid paper

Keep the rolling temperature at  $120^{\circ}\text{C}$ , and measure the properties of aramid paper at room temperature at rolling pressures of 0.3MPa, 0.2MPa, and 0.1MPa. Relatively Dielectric constant and dielectric loss, The results are shown in Table 1.

Table 1. The relative permittivity and dielectric loss of aramid paper change with roll pressure when the temperature is  $120^{\circ}\text{C}$

Roll pressure(MPa)	Relative permittivity	Dielectric loss(%)
0.1	1.946	0.62
0.2	1.958	0.61
0.3	1.963	0.59

Combined with the above test results, it can be seen that as the rolling pressure increases, the dielectric constant of meta-aramid paper shows a trend of first increasing and then decreasing. This is because higher rolling pressure helps to improve the paper's properties. Density, reducing the dielectric constant; at the same time, it was found that the rolling pressure has no significant impact on the dielectric

loss. After reviewing the literature, the reason may be that the rolling pressure usually only affects the surface of the paper, and has a greater impact on the internal structure and performance of the paper. Small. 0.3MPa is a more suitable rolling pressure.

### 2.1.2.2 Effect of rolling temperature on dielectric properties of aramid paper

Keep the rolling pressure at 0.3MPa, and measure the dielectric constant and dielectric loss of aramid paper at rolling temperatures of 120°C, 160°C, and 200°C. The results are shown in Table 2.

**Table 2.** The change of relative permittivity and dielectric loss of aramid with rolling temperature when the roller pressure is 0.3MPa

Roll temperature(°C)	Relative permittivity	Dielectric loss(%)
120	2.073	0.61
160	2.216	0.98
200	2.394	1.41

It can be seen that as the temperature increases, the relative dielectric constant of aramid paper continues to increase, because the increase in rolling temperature will affect the molecular structure and arrangement of meta-aramid paper, causing the average distance of the molecules to become smaller. , causing the dielectric constant of the paper to gradually increase. At the same time, the increase in rolling temperature will also cause the mobility of the aramid paper molecular chain to increase, which will increase the energy loss inside the material, thereby gradually increasing the dielectric loss. In addition, the electrical conductivity of materials increases at high temperatures, further increasing dielectric losses.

By comprehensively analyzing this result and the changes in dielectric strength and tensile strength of aramid paper at different rolling temperatures, it is concluded that 200°C is a more suitable rolling temperature.

### 2.1.3. Preparation of nano-doped aramid paper

#### 2.1.3.1 Preparation of nanodispersion containing nanoparticles

Due to their small size and high surface energy, nanoparticles are prone to agglomeration during preparation and transportation. Adding surfactants such as sodium dodecylbenzene sulfonate as dispersion and using ultrasonic treatment can effectively avoid the occurrence of agglomeration. As a surfactant, sodium dodecylbenzene sulfonate can be adsorbed on the surface of nanoparticles and provide repulsion between nanoparticles to prevent agglomeration. Ultrasonic treatment uses the shock waves and micro-jet generated by its cavitation to crush the agglomerated particles, thereby reducing agglomeration.

Add 5.00g of weighed sodium dodecylbenzene sulfonate particles to 250 mL of distilled water, stir magnetically for 300 s, stir at a temperature of 50°C, and rotate at a speed of 1200 r/min to prepare a nanodispersion for later use.

Add the nanoparticles to the above dispersion and stir magnetically for 10 minutes at a stirring temperature of 50°C and a rotation speed of 1200 r/min. The nanomixed solution was subjected to ultrasonic stirring treatment with an ultrasonic power of 400W and a time of 30 minutes.

The doping concentration can be adjusted by changing the mass of the added nanoparticles.

Add the nanoparticles to the above dispersion and stir magnetically for 10 minutes at a stirring temperature of 50°C and a rotation speed of 1200 r/min. Changing the mass of nanoparticles added in this step can control the doping concentration.

The nanomixed solution obtained above was subjected to ultrasonic stirring treatment with an ultrasonic power of 400W and a time of 30 minutes.

#### 2.1.3.2 Preparation of retention aids

Adding retention aids can reduce nanoparticle loss during the papermaking process. In order to ensure the uniformity of the paper, the retention aid cationic polyacrylamide will cationize the nanoparticles, thereby increasing the adsorption of filler particles and pulp fibers, acting as a flocculation, thereby significantly improving the retention rate of nanoparticles in the paper. .

Weigh 0.04g of cationic polyacrylamide, add it to a beaker containing 200mL of distilled water, place it in a magnetic stirrer and stir for 40 minutes at 50°C and 1200r/min to obtain a uniformly dissolved and dispersed liquid for later use.

#### 2.1.3.3 Nanoparticles are evenly dispersed in aramid slurry

Add the nanomixed solution prepared above to the uniformly mixed aramid fiber slurry. The ratio of fibril fibers to chopped fibers is 7:3. Stir magnetically for 10 minutes. The stirring temperature is 50°C and the rotation speed is 500r/min.

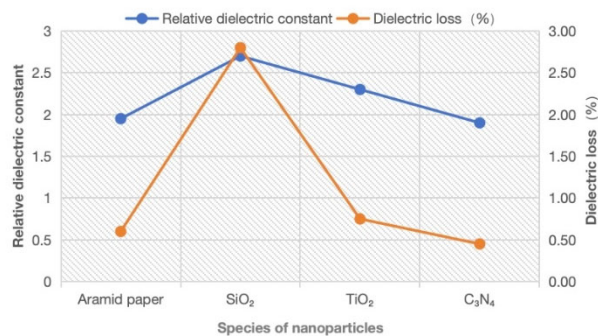
Add the above mixed liquid and retention aid to the wet forming machine, and other steps are the same as the production process of ordinary aramid paper.

## 2.2. Research on the properties of nano-modified aramid paper

After reviewing the literature, it is known that the optimal nanoparticle doping amount that can make the dielectric strength and tensile strength of modified aramid paper better is to add 15% SiO<sub>2</sub>, 3% TiO<sub>2</sub>, and 4% C<sub>3</sub>N<sub>4</sub>. Doping concentration studies were conducted to determine the optimal nanoparticle species.

### 2.2.1. Relative dielectric constant and dielectric loss of different nano-doped aramid papers at optimal concentrations

The relative dielectric constant and dielectric loss of SiO<sub>2</sub>, TiO<sub>2</sub> and C<sub>3</sub>N<sub>4</sub> nanoparticle-doped paper at the optimal doping concentration are shown in Figure 2. Here, the measured data of aramid paper without nanoparticle doping are used as a comparison group.



**Figure 2.** The relative dielectric constant and dielectric loss of paper doped with different nanoparticles at the optimum doping concentration

The data shows that the dielectric constants of the three nano-doped modified papers are all between 1.9-2.8, while

the relative dielectric constant of the transformer oil is between 2.2-2.4. The two are relatively close and can work well together. At the same time, it was found that the dielectric loss of SiO<sub>2</sub>-doped modified paper increased significantly, and the dielectric loss of TiO<sub>2</sub>-doped composite paper also increased slightly. Only the dielectric loss of C<sub>3</sub>N<sub>4</sub>-modified paper decreased compared with the control group. Exhibits expected ideal dielectric properties.

This result occurs the reason is that the C<sub>3</sub>N<sub>4</sub> filler is two-dimensional and flaky, which can block charges and reduce the degree of polarization of the paper surface, thereby reducing the dielectric loss. TiO<sub>2</sub> filler has strong polarity, and the 15% doping amount of SiO<sub>2</sub> particles introduces more dipole groups, which enhances the dipole polarization characteristics, resulting in a large increase in dielectric loss.

### 2.2.2. Determination of the best nanofiller to improve the dielectric properties of composite paper

Based on the above research, it was found that 4% doping level C<sub>3</sub>N<sub>4</sub> composite paper has a relative dielectric constant that is close to that of transformer oil, and its dielectric loss is lower than that of unmodified paper. It can be used with transformer oil while ensuring lower dielectric loss. Basically For the intended purpose of compounding, it was selected as a nanofiller to improve the dielectric properties of aramid fiber.

### 2.3. Summary of this chapter

This chapter completes the manufacturing of ordinary meta-aramid paper in the laboratory, focusing on the impact of the rolling process on the performance of meta-aramid paper. In the ratio of fibril: chopped fiber = 7:3 (dry weight) The optimal rolling temperature and pressure of lower meta-aramid paper are 200°C and 0.3Mpa respectively.

Under the above-mentioned optimal process conditions, the manufacturing of nano-filler-doped meta-aramid paper was completed, and three nano-filler-doped meta-aramid papers, SiO<sub>2</sub>, TiO<sub>2</sub>, and C<sub>3</sub>N<sub>4</sub>, were compared with those without nano-fillers at the optimal addition amount. Based on the relative dielectric constant and dielectric loss of doped aramid paper, an optimal nano-filler filler was selected: 4% concentration C<sub>3</sub>N<sub>4</sub>. The doped paper has relatively good dielectric properties.

### Acknowledgment

This project is supported by China National University Student Innovation & Entrepreneurship Development Program (S202310079189).

### References

- [1] I. Fofana, V. Wasserberg, H. Borsi, et al. Challenge of mixed insulating liquids for use in high-voltage transformers. II. Investigations of mixed liquid impregnated paper insulation[J]. 2002, 18(4): 5-16.
- [2] J. K. Pandey, S. H. Ahn, C. S. Lee, et al. Recent advances in the application of natural fiber based composites[J]. *Macromolecular Materials and Engineering*, 2010, 295(11): 975-989.
- [3] W. Volksen, R. D. Miller, G. Dubois. Low dielectric constant materials[J]. *Chemical Reviews*, 2010, 110(1): 56-110.
- [4] Y. J. Lee, J. M. Huang, S. W. Kuo, et al. Low-dielectric, nanoporous polyimide films prepared from PEO-POSS nanoparticles[J]. *Polymer*, 2005, 46(23): 10056-10065.
- [5] D. Douroumis, I. Onyesom, M. Maniruzzaman, et al. Mesoporous silica nanoparticles in nanotechnology[J]. *Critical Reviews in Biotechnology*, 2013, 33(3): 229-245.
- [6] S. Salimian, A. Zadhoush, A. Mohammadi. A review on new mesostructured composite materials: Part I. synthesis of polymer-mesoporous silica nanocomposite[J]. *Journal of Reinforced Plastics and Composites*, 2018, 37(7): 441-459.
- [7] Kopper K.P.,Küpper D.,Reeve R.,et al.Chemically selective modification of spinpolarization in ultrathin ferromagnetic films:Microscopic theory and macroscopicexperiment.*Phys.Rev.B* 2009,80,1956–1960.
- [8] Tang C, Zhang S, Xie JY, et al. Molecular simulation and experimental analysis of Al<sub>2</sub>O<sub>3</sub>-nanoparticle-modified insulation paper cellulose[J].*IEEE Transactions on Dielectrics&Electrical Insulation*,24(2):1018-1026.
- [9] Tang C, Li X, Yin F, et al. The Performance Improvement of Aramid Insulation Paper by Nano-SiO<sub>2</sub> Modification[J].*IEEE Transactions on Dielectrics&ElectricalInsulation*,24(4):2400-2409.
- [10] H. Tsukioka, E. Ohe, Y. Kamata, et al. Development of low dielectric constant pressboard[C]. *Proceedings of the Twenty-First Symposium on Electrical Insulating Materials. IEEE*, 1988: 311-314.
- [11] Yang B, Wang L, Zhang M, et al. Fabrication, applications, and prospects of aramid nanofiber[J]. *Advanced Functional Materials*, 2020,30(22): 1-28.
- [12] Liao RJ, Li X, Yang LJ, et al. Effect of Intermediate aramid staple fiber/pulp Ratio on Performance of Aramid insulating Paper [J]. *High Voltage Technology*, 2015,41(02): 364-373.
- [13] Yang B, Hui LF, Liu Q, et al. Effect of Hot pressing on Properties of aramid fiber paper [J]. *Journal of Tianjin University of Science and Technology*, 2020:1-5.
- [14] Tang C, Li X, Tang Y, et al. Agglomeration mechanism and restraint measures of SiO<sub>2</sub> nanoparticles in meta-aramid fibers doping modification via molecular dynamics simulations[J]. *Nanotechnology*, 2020,31(16): 165702.
- [15] Tang C, Li X, Yin F, et al. The performance improvement of aramid insulation paper by nano-SiO<sub>2</sub> modification[J]. *Institute of Electrical and Electronics Engineers*, 2017,24(4): 2400-2409.
- [16] Browne T C, Crotogino R H, Douglas W J M. The effect of paper structure onbehavior in a calendar nip[J]. *Journal of Pulp and Paper Science*, 1995, 21(10):343-347.
- [17] Retulainen E, Moss P, Nieminen K. Effect of calendaring and wetting on paperproperties[J]. *Journal of Pulp and Paper Science*, 1997, 23(1):34-39