Study on Dielectric Material for Generating Ozone by Dielectric Barrier Discharge

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Abstract. Dielectric barrier discharge is mainly used to produce ozone in industry. The dielectric plays an important role in this form of discharge. Because of their good physical and chemical properties, some kinds of ceramic material and enamel material have been studied and applied as the dielectric. Experiments show that as frequency increases, dielectric constant and loss angle tangent of all ceramic samples decrease. For samples with larger dielectric constant, dielectric constant decreases faster, and the magnitude of the decrease is larger. When the frequency is high, dielectric constant and the loss angle tangent basically stabilize. At the same frequency, the loss angle tangent of ceramic samples with high dielectric constant is also higher. The dielectric constant and loss angle tangent of different ceramic samples differ greatly at low frequency, while the difference is relatively reduced at high frequency. From the perspective of electrical performance, ceramic dielectrics are not much superior to enamel dielectrics. Enamel material is more advantageous than ceramic material.

1. Introduction
Ozone, as a strong oxidant, will not produce carcinogenic secondary pollutants, and is widely used in the treatment of drinking water, industrial wastewater and other fields. Dielectric barrier discharge (DBD) is mainly used to produce ozone in industry. The dielectric plays an important role in this form of discharge. The effects of the dielectric are as follows: to strengthen the electric field strength of the air gap, to prevent the breakdown of the gap, to make the electric field of air gap uniform, and to expand the discharge area.

2. Overview
There are many indicators describing the properties of materials, including physical properties (such as density, porosity, water absorption), mechanical properties (such as strength, elasticity, hardness), and thermal properties (such as specific heat, thermal conductivity, thermal expansion coefficient), electrical properties (such as dielectric constant, electrical strength, dielectric loss) and chemical stability (mainly refers to corrosion resistance) and so on[1]. In general, in order to facilitate the generation of ozone, it is expected that the dielectric has strong thermal conductivity, thermal expansion coefficient close to the electrode material, high dielectric constant, high electrical strength, small dielectric loss and strong corrosion resistance.

3. Electrical properties of ceramic dielectrics

3.1. Composition of ceramic material
Because of their good physical and chemical properties, some kinds of ceramic material have been studied and applied as the dielectric[1]. The distribution of ceramic raw materials is very wide, and its composition is quite complicated. From the perspective of mineral composition of raw materials, they can be roughly divided into clay raw materials, silica raw materials, feldspar raw materials, calcium raw materials, magnesium raw materials, etc., each of which contains a variety of ingredients[1]. The ceramic material used in the experiment is magnesium. The ingredient mainly include magnesiumolivine and bluestone, and some other ingredients are added. By changing the proportion of different ingredients, a series of 6 ceramic plate samples with different numbers are made, and the numbers are set as A, B, C, D, F, H.

3.2. Measurement of dielectric constant and loss angle tangent
When the samples are treated as parallel-plate capacitors, they are actually treated as loss-making capacitors[2-3]. Their equivalent parallel capacitance $C$ and loss angle tangent $\tan\delta$ are measured. Then the dielectric constant can be calculated by using the formula. Because the sample have been considered parallel plate capacitors, the calculation formula for a circular electrode is as follows:

$$C_0 = \frac{\varepsilon_0 S}{\delta} = \frac{\varepsilon_0 \pi d^2}{4\delta} = \frac{6.954 \times d^2}{\delta} \times 10^{-3} \text{(pF)}$$

where

- $\varepsilon_0$ -- Permittivity of vacuum, $8.854 \times 10^{-12} F/m$
- $S$ -- Electrode area, $mm^2$
- $d$ -- Electrode diameter, $mm$
- $\delta$ -- Sample thickness, $mm$

The calculated vacuum capacitance of each sample is shown in Table 1.

| Serial number | A  | B  | C  | D  | F  | H  |
|---------------|----|----|----|----|----|----|
| Diameter (mm) | 51.82 | 47.57 | 45.92 | 54.00 | 45.45 | 47.11 |
| Thickness (mm) | 1.71 | 1.43 | 1.60 | 1.58 | 1.72 | 1.55 |
| $C_0$(pF) | 10.92 | 11.00 | 9.165 | 12.83 | 8.352 | 9.957 |

In order to compare the decreasing rate of dielectric constant and loss angle tangent of each sample with the frequency, the dielectric constant and loss angle tangent values of each sample at different frequencies were divided by their initial values at a certain low frequency, and then these percentages were plotted into curves, as shown in Figure 1 and Figure 2.

![Figure 1. Velocity curve of dielectric constant at different frequency](image1)
![Figure 2. Velocity curve of loss angle tangent with frequency](image2)

It can be seen that the rate of decrease of dielectric constant and loss angle tangent of different samples is different. As can be seen from Figure 1, samples with relatively high dielectric constant, such
as B and F, reduce dielectric constant faster and with a larger reduction range, while samples with the smallest dielectric constant, D, change with a small frequency range at low frequency. No matter what kind of medium, when the frequency is greater than 5kHz, dielectric constant is basically stable. A similar pattern can be seen in Figure 2, except that the difference between samples is not as big as in Figure 2. Moreover, when the frequency is greater than 20kHz, the tangent of loss angle is basically stable. As a result of the above difference in change rates, it can also be seen that the dielectric constant or loss angle tangent of different samples varies greatly at low frequency, while the difference is relatively reduced at high frequency.

4. Electrical property of enamel medium

4.1. Composition of enamel medium
Enamel material is a combination of inorganic glass glaze and metal substrate, so it combines the characteristics of both[4]. In recent years, enamel has been used as a dielectric in ozone generator because of its simple manufacturing process, high electrical strength, large dielectric constant value and strong corrosion resistance[5]. In the experiment, the manufacturer was commissioned an enamel sample on 1mm thick steel plate, and the thickness of the enamel layer was about 0.3mm.

4.2. Measurement of dielectric constant and loss angle tangent
The measurement method is to apply high-frequency power to experimental sample, record voltage, current, and phase difference between them with an oscilloscope, and then calculate dielectric constant and loss angle tangent of the sample. The schematic diagram of measurement circuit is shown in Figure 3. Regulator B and transformer T are used to produce high voltage with adjustable amplitude. R1 is the overcurrent protection resistance to prevent sample breakdown. R2 is sampling resistance used to measure current. P is high voltage attenuation probe, which provides voltage measurement signal for oscilloscope. OSC is an oscilloscope used to measure electrical parameters in experiment.

4.2.1. Voltage and current waveform. The waveform is shown in Figure 4. It can be seen that current waveform leads voltage waveform, indicating that experimental sample is capacitive load. In addition, current waveform is not a smooth sine curve, indicating that equivalent capacitance and resistance in the equivalent RC parallel circuit of sample are not completely stable, but will fluctuate with fluctuation of voltage.
4.2.2. **Dielectric constant and loss angle tangent.** The measured value of sample voltage, current and power factor angle, as well as the calculated value of dielectric constant and loss angle tangent are shown in Table 2. It can be seen that dielectric constant of enamel sample decreases with the increase of voltage, which indicates that equivalent capacitance and the equivalent resistance of the sample are not completely stable, but vary with the change of voltage. It can also be seen that the loss tangent of enamel is still large, which indicates that when it is used as an insulating medium, its electrical conduction current will be larger and the heat generation will be larger.

| Voltage (V) | Current (μA) | Phase difference(°) | Equivalent capacitance(pF) | Dielectric constant | loss angle tangent |
|------------|-------------|---------------------|-----------------------------|--------------------|--------------------|
| 511.4      | 49.7        | 77.4                | 290.1                       | 18.5               | 0.20               |
| 1086       | 99.7        | 72.0                | 264.4                       | 16.9               | 0.29               |
| 2059       | 172.6       | 73.8                | 244.6                       | 15.6               | 0.26               |
| 3091       | 230.1       | 73.8                | 217.2                       | 13.9               | 0.26               |
| 4048       | 286.8       | 75.6                | 209.2                       | 13.4               | 0.23               |

4.2.3. **Breakdown field strength.** Breakdown field strength is measured by continuously increasing voltage applied to experimental sample in electrical circuit similar to Figure 1 until sample breakdown. The voltage value at sample breakdown is recorded and divided by the thickness of sample, which is breakdown field strength. The breakdown voltage values and the breakdown field strength values of the enamel samples are shown in Table 3.

| Number of experiments | Breakdown voltage (kV) | Breakdown field strength (kV/mm) | Average value |
|-----------------------|------------------------|----------------------------------|---------------|
|                       | 1                      | 2                                | 3             | 4             | 5             | 6             | 7             | 8             | Average value |
| Breakdown voltage (kV)| 8.6                    | 9.2                              | 8.4           | 9.0           | 8.7           | 10.0          | 8.8           | 10.0          | 9.1            |
| Breakdown field strength (kV/mm)| 28.7  | 30.7  | 28.0  | 30.0  | 29.0  | 33.3  | 29.3  | 33.3  | 30.3            |

Average breakdown field strength shown in Table 3 reaches 30.3kV/mm, which shows that the electrical strength level of enamel samples can meet the requirement.

5. Conclusion

- As frequency increases, dielectric constant and loss angle tangent of all ceramic samples decrease. Dielectric constant and loss angle tangent of different samples decrease at different speeds. For samples with larger dielectric constant, dielectric constant decreases faster, and the magnitude of the decrease is larger. When the frequency is high, dielectric constant and the loss angle tangent basically stabilize.

- At the same frequency, the loss angle tangent of ceramic samples with high dielectric constant is also higher. Although high dielectric constant is an advantage, large loss angle tangent leads to more energy loss and overheating. The dielectric constant and loss angle tangent of different ceramic samples differ greatly at low frequency, while the difference is relatively reduced at high frequency.

- Dielectric constant of some ceramic samples is very high at low frequency, which is much larger than that of the enamel samples. At the same time, loss angle tangent is also very large, which also exceeds many of the enamel samples. Electrical strength of enamel sample can be compared with that of electric porcelain material and is no worse than that of ceramic sample. Therefore, from the perspective of electrical performance, ceramic dielectrics are not much superior to enamel dielectrics.

- For the production of electrode device that is closely combined with dielectric, especially thin electrode plate and dielectric layer, enamel material is more advantageous than ceramic material.

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