Design and Analysis of Temperature Dependence on Dielectric Behavior of Polymer Capacitor

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Abstract: The dielectric material of capacitor depend on the capacitance per unit volume, energy stored per unit volume, the power dissipated per unit volume, the temperature coefficient of capacitance, the operation temperature and the frequency of the applied field. This paper introduces the equivalent circuit of the dielectric behavior of polymer capacitor at 51.2kHz, 1MHz frequency depend on the dielectric constant and dielectric loss. When the operating temperature of capacitor changes, the capacitance and conductance value of general model circuit changed according to the temperature 350°C and 380°C.

Keywords: dielectric material, capacitors, frequency and temperature.

1. INTRODUCTION

Capacitor is an electronic passive element that can store electric charge, filter and regulate the electrical energy and current flow. The main purpose of use for the capacitor is to store electrical energy and conduct the alternating current and block the dc current. The unit of the capacitance is the farad (F).

\[
1 \text{ farad} = \frac{1 \text{ coulomb}}{1 \text{ volt}} \quad \text{equation (1)}
\]

So the amount of electric charge stored equation is \( Q = C/V \).

Where,

- \( Q \) is the electric charge in coulombs
- \( C \) is the capacitance in farad
- \( V \) is the voltage between the plates in volts
The amount of the electric charge stored is directly proportional to the capacitance of and inversely proportional to its applied voltage.

There are many different of capacitors but all of the capacitor types are the same basic structures. Opposite charge of two parallel metal electrodes are separated by insulating material called dielectric. When a voltage is applied to the parallel plate capacitor, electric field is present in dielectric medium that cause the polarization effect due to induced dipole moment in dielectric material. The polarization can store the charge in dielectric material and produce a mechanical force between the plates.

1.1. Parameter of capacitor

The amount of parallel plate capacitor is determined by the equation:

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$  \hspace{1cm} \text{equation (3)}

Where C is the capacitance of the capacitor, ε_0 is the absolute permittivity, ε_r is the relative permittivity, A is the area of the plate and d is the distance between the plates. A large capacitance is acquired to select high dielectric constant, large dielectric area and small d.

In Engineering design consideration, to select the capacitor used for different types of application the important parameter is the dielectric material.

1.2. Different Types of Capacitors

The different types of capacitors are following.

1. Electrolytic Capacitor
2. Mica Capacitor
3. Paper Capacitor
4. Film Capacitor
5. Non-Polarized Capacitor

The dielectric material of capacitor depend on the capacitance per unit volume, energy stored per unit volume, the power dissipated per unit volume, the temperature coefficient of capacitance, the operating temperature and the frequency of the applied field.

The capacitance per unit volume Cvol (or) volumetric efficiency of dielectric material represents by the equation

$$C_{vol} = \frac{\varepsilon_0 \varepsilon_r}{d^2}$$  \hspace{1cm} \text{equation (4)}

Where ε_0 is the absolute permittivity, ε_r is the relative permittivity and d is the thickness of dielectric material.

Another Engineering consideration in selection of dielectric material is the safety working voltage that is related to the maximum energy that can be stored per unit volume, Evol and power dissipation per unit volume, Wvol.

$$E_{vol} = \frac{\varepsilon_0 \varepsilon_r}{2\eta^2} E_{br}^2$$  \hspace{1cm} \text{equation (5)}

Where ε_0 is the absolute permittivity, ε_r is the relative permittivity, Ebr is break down field of dielectric medium and η is the safety factor.

$$W_{vol} = \frac{E_{br}^2}{\eta^2} \varepsilon_0 \varepsilon_r \tan \delta$$  \hspace{1cm} \text{equation (6)}

Where ε_0 is the absolute permittivity, ε_r is the relative permittivity, Ebr is break down field of dielectric medium, tanδ is dielectric loss factor and η is the safety factor.

In Engineering consideration of selection dielectric material, the other important factors temperature coefficient of capacitance (TCC) and their application frequency range.
2. COMPUTATIONAL METHODS

2.1. Calculation of the general equivalent circuit of dielectric behavior for fluorepolymer

From figure (1), at 350°C and 51.2 KHz for pure PVDF

\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \]
\[ \varepsilon_r = 6.5 \]
\[ \tan \delta = 0.05 \]

Assume capacitance \( C = 300 \text{ nF} \)

\[
G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan \delta}{d} = \omega C \tan \delta = 2 \times \pi \times 51.2K \times 300n \times 0.05 = 4.823 \mu \Omega
\]
\[ R_p = 203 \Omega \]

From figure (1), at 380°C and 51.2 KHz for pure PVDF

\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \]
\[ \varepsilon_r = 6.6 \]
\[ \tan \delta = 0.08 \]

Assume \( C = 300 \text{ nF at 350°C} \)

\[
C_{380} = \frac{C_{350}}{\varepsilon_0_{350} \varepsilon_r_{350}} = \frac{300n}{6.6} = 304.6 \mu \text{F}
\]
\[
G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan \delta}{d} = \omega C \tan \delta
\]
\[ = 2 \times \pi \times 51.2\K \times 304.6n \times 0.08 \]
\[ = 7.835m\Omega \]
\[ R_3 = 127\Omega \]

![Figure 3. at 380 C° and 51.2 KHz for pure PVDF](image)

### 2.2. Calculation of the general equivalent circuit of dielectric behavior for La\(_{0.7}\)Sr\(_{0.3}\)MnO\(_3\) polymer nanocomposite

From figure (1), at 350 C° and 1MHz for pure PVDF

- \( \varepsilon_0 = 8.85 \times 10^{-12} F/m \)
- \( \varepsilon_r = 6.25 \)
- \( \tan\delta = 0.03 \)

Assume capacitance \( C = 300 \) nF

- \( G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan\delta}{d} \)
- \( = \omega C \tan\delta \)
- \( = 2 \times \pi \times 1M \times 300n \times 0.03 \)
- \( = 56.52 \, m\Omega \)

\[ R_p = 17.59\Omega \]

![Figure 4. at 350 C° and 1MHz for pure PVDF](image)

From figure (1), at 380 C° and 1MHz for pure PVDF

- \( \varepsilon_0 = 8.85 \times 10^{-12} F/m \)
- \( \varepsilon_r = 6.28 \)
- \( \tan\delta = 0.025 \)

Assume \( C = 300 \) nF at 350 C°

\[ C_{380} = C_{350} \frac{\varepsilon_r_{380}}{\varepsilon_r_{350}} \]
\[ C_{380} = 300n \frac{6.28}{6.03} = 312.4nF \]

- \( G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan\delta}{d} \)
- \( = \omega C \tan\delta \)
- \( = 2 \times \pi \times 1M \times 312.4n \times 0.025 \)
- \( = 49.02\, m\Omega \)

\[ R_p = 20\Omega \]

![Figure 5. at 380 C° and 1MHz for pure PVDF](image)

From figure (1), at 350 C° and 51.2KHz for composite
\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \]
\[ \varepsilon_r = 28.5 \]
\[ \tan \delta = 0.08 \]

Assume capacitance \( C = 300 \text{ nF} \)

\[ G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan \delta}{d} \]
\[ = \omega C \tan \delta \]
\[ = 2 \times \pi \times 51.2 \times 300 \times 0.08 \]
\[ = 7.7168 \mu \Omega \]
\[ R_p = 129 \Omega \]

![Figure 6. at 350°C and 51.2KHz for composite](image)

From figure (1), at 380°C and 51.2KHz
\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \]
\[ \varepsilon_r = 32 \]
\[ \tan \delta = 0.17 \]

Assume \( C = 300 \text{ nF} \) at 350°C

\[ C_{350} = C_{380} \frac{\varepsilon_{350}}{\varepsilon_{380}} \]
\[ C_{380} = 300 \times \frac{28.5}{32} = 336.8 \mu \text{F} \]
\[ G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan \delta}{d} \]
\[ = \omega C \tan \delta \]
\[ = 2 \times \pi \times 51.2 \times 336.8 \times 0.17 \]
\[ = 18.409 \mu \Omega \]
\[ R_p = 54.32 \Omega \]

![Figure 7. at 380°C and 51.2KHz for composite](image)

From figure (1), at 350°C and 1MHz for composite
\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m} \]
\[ \varepsilon_r = 26 \]
\[ \tan \delta = 0.05 \]

Assume capacitance \( C = 300 \text{ nF} \)

\[ G_p = \frac{\omega \varepsilon_0 \varepsilon_r \tan \delta}{d} \]
\[ = \omega C \tan \delta \]
\[ = 2 \times \pi \times 1 \times 300 \times 0.05 \]
\[ = 4.71 \mu \Omega \]
\[ R_p = 212 \Omega \]
\[ C_{350} = 300 \text{ nF} \]
From figure (1), at 380 °C and 1MHz

\[ \varepsilon_r = 8.85 \times 10^{-12} \text{ F/m} \]
\[ \tan \delta = 0.08 \]
Assume \( C = 300 \text{ nF} \) at 350 °C

\[ C_{380} = C_{350} \frac{\varepsilon_{380}}{\varepsilon_{350}} \]
\[ C_{380} = 300 \times \frac{6.5}{27} = 311.54 \text{ nF} \]

\[ G_p = \frac{\omega \varepsilon_r c_0 \tan \delta}{d} \]
\[ = \frac{\omega C \tan \delta}{2 \pi \times 1M \times 311.5 \times 0.08} \]
\[ = 156.52 \text{ m\Omega} \]
\[ R_p = 6.38 \Omega \]

From figure 8, at 350 °C and 1MHz for composite

3. CONCLUSION

When the alternating voltage is applied to the polymer dielectric material of the parallel plate capacitor, the dielectric constant and dielectric loss appears in the dielectric material. The dielectric behavior depends on the operating temperature and the frequency of induced electric field due to the sinusoidal ac voltage. At frequency 51.2kHz of fluoropolymer, dielectric constant is increasing \( (\varepsilon_r = 6.5) \) from 350°C to \( (\varepsilon_r = 6.6) \)380°C and dielectric loss factor is also increasing \( (\tan \delta = 0.05) \) from 350°C to \( (\tan \delta = 0.08) \)380°C. In the dielectric behavior model equivalent circuit, \( R_p \) value is decreased from \( (203 \Omega) \) at 350°C to \( (127 \Omega) \) at 380°C. But the capacitance value is increased from 300nF at 350°C to \( (304.6 \text{ nF}) \) at 380°C. At frequency 1MHz, the capacitance value is increased from 300nF to 312.4nF but the \( R_p \) value is increased from 17.69Ω to 20Ω. At frequency 51.2kHz of \( \text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3 \) polymer nanocomposite, the capacitance value is increased from 300nF to 336.8nF and the \( R_p \) value is decreased from 129Ω to 54.32Ω. At frequency 1MHz of \( \text{La}_{0.7}\text{Sr}_{0.3}\text{MnO}_3 \) polymer nanocomposite, the capacitance value is increased from 300nF to 311.54nF and the \( R_p \) value is decreased from 212Ω to 6.3Ω.

4. REFERENCES
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