# Effect of Humidity on the Air-Dielectric Interface Breakdown under Nanosecond Pulse with Fluid Simulation

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***Abstract*—The influence of humidity on the air-dielectric interface discharge under nanosecond pulse is investigated with fluid simulation. The space distribution of electric field and particles are obtained. The simulation results show that the threshold of breakdown at air-dielectric interface increases with the growth of ratio of $H_2O$ in a certain range, which is in good agreements with experimental data. The theory analyses are done to study the evolution of discharge. Compared with $O_2$, the attachment rate of $H_2O$ is larger, and the ionization rate of $H_2O$ is smaller. Therefore, the effective ionization rate decreases with the ratio of $H_2O$. Therefore, the surface flashover breakdown is more difficult to occur in humid air. These results can provide a deep understanding of the mechanism of air-dielectric interface breakdown.**

***Keywords*—humidity, surface flashover, fluid simulation**

## I. INTRODUCTION

Gas insulation is frequently used in various electrical equipment of high voltage transmission and distribution [1]. With the promotion of Ultra-high voltage (UHV), the air-dielectric interface becomes the vulnerable part of insulation system. The breakdown characteristics of air-dielectric interface has been studied by many researchers. The threshold of breakdown is often affected by electrode structure, humidity, pressure and temperature[2-4]. It has been shown that the humidity has a great influence on discharge. The propagation speed of streamer with different ratio of humidity at air-dielectric interface was investigated by Meng. The experimental data indicate that the speed of discharge decreases with the growth of humidity [5]. Besides, the influence of humidity on air gap discharge characteristics was also obtained. The threshold of breakdown increases with the growth of humidity when the air gap is short [6]. A numerical model is established to investigate the development of streamer in long air gap with different air humidity. The results show that the increase of air humidity impedes the discharge [7]. However, the evolution of air-dielectric interface breakdown with different ratio of humidity is still unclear. Therefore, a fluid simulation is performed with PASSKEy [8] to study the effect of air humidity on the air-dielectric interface breakdown under one atmosphere.

## II. SIMULATION MODEL AND RESULTS

The model of air-dielectric interface breakdown under nanosecond pulses is shown in Fig. 1. A flat electrode is used with an electrode gap distance of 20 mm. The neutral reactions of $H_2O$ are obtained from Atsushi's work [9]. The elastic, ionization, excitation and attachment cross sections of $N_2$, $O_2$ and $H_2O$ are obtained from the Morgan database [10]. The initial electrons are set at the interface of cathode-air-dielectric as a seed, with a density of $1\times10^{19}$ $m^{-3}$. In order to improve computational efficiency and reduce simulation costs, we performed a refined calculation of the dielectric interface. The smallest size of mesh is 8 μm×8 μm. The time step is 5 fs.

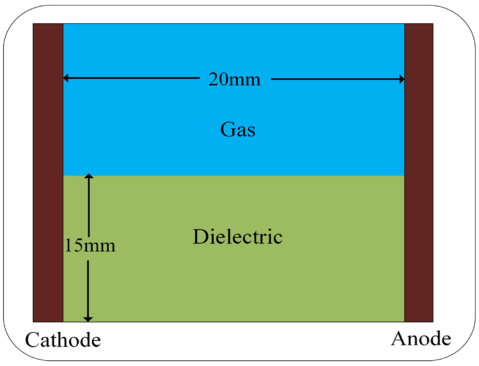


Fig.1 Air-dielectric discharge model with uniform electric field

Figure 2 shows the average energy of electrons $T_e$ with time $t$. In the dry air ($\alpha$=0%, which is the ratio of $H_2O$ in the air), the maximum value of 11 eV is reached at 12 ns. While in the humid air ($\alpha$=2% and 4%), the maximum value of approximately 10.5 eV is reached at 13 ns. The values of $T_e$ in dry and humid air are almost same, but it takes longer time to reach its maximum in the humid air.

The trend of the electric field variation with time with different ratio of humidity is shown in Fig. 3 . The electric field of dry air significantly higher than moist air after 8 ns and reaches its maximum value earlier. Before breakdown (12 ns), the electric field of air with 2% $H_2O$ is slightly higher than that of air with 4% $H_2O$. Figure 4 shows the variation of density of electrons, where dry air exhibits significantly higher density of electrons than that of humid air. In addition, the density of electron decreases as α increases.

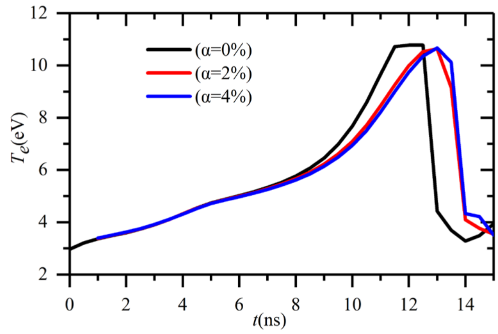


Fig. 2 Average energy of electron $T_e$.

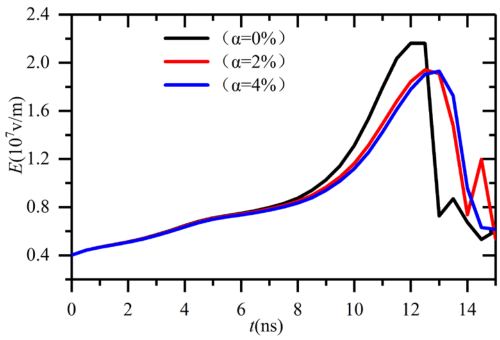


Fig. 3. Strength of electric field.

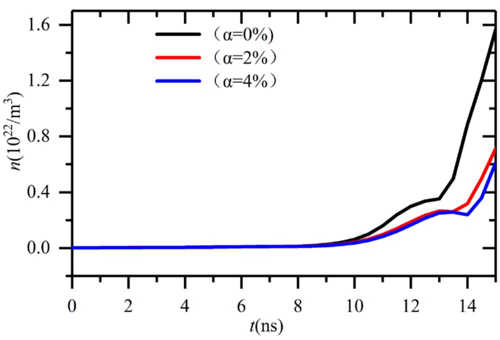


Fig. 4 Density of electrons.

## III. Analysis and Discussion

In this work, the energy of electrons is assumed to obey the Maxwell distribution[11].

$$f\left(W\right)=\frac{2}{\sqrt{\pi}}\left(k_bT_e\right)^{-\frac{3}{2}}W^{\frac{1}{2}}e^{\left(\frac{W}{k_bT_e}\right)} \tag{1}$$

Eq. (2) shows the attachment rate and ionization rate [12]:

$$v_{a,i}=n_g\int_0^{\infty}f\left(W\right)\sigma_{a,i}\sqrt{\frac{2W}{m}}dW \tag{2}$$

Where $k_b$ is the Boltzmann constant, $n_g$ is the density of neutral gas, $\sigma_a$ is the attachment cross sections, $\sigma_i$ is the ionization cross sections, and $m$ is the mass of electron. The ionization rate and attachment rate of $N_2$, $H_2O$ and $O_2$ are

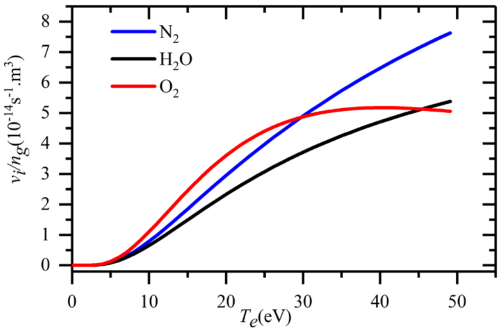


Fig. 5 Ionization rate.

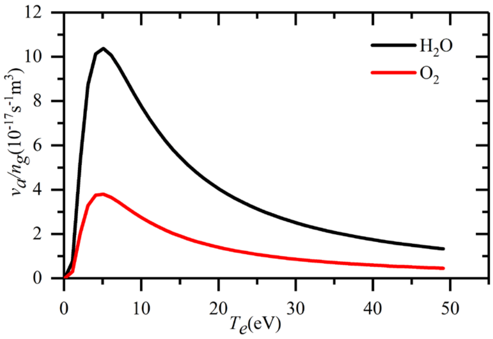


Fig. 6 Attachment rate.

shown in Fig. 5 and Fig. 6 .When $T_e$ equals 10 eV, the ionization rate of $H_2O$ and $O_2$ are similar, but the attachment rate differs greatly, which will directly affect the effective ionization rate.

As shown in Fig. 2, the average energy of electrons under different humidity conditions is similar before 8 ns, generally less than 5 eV. In this period, the distribution of electric field changes little due to the weak space charge effect. After 8 ns, the density of electron reaches $10^{20}$ $m^{-3}$. With the development of space charge, the distribution of electric field changes. Figure 7 and 8 show the distribution of space charge and electric field when $t$ = 12 ns with the ratio of $H_2O$ $\alpha$=0% and 2%.

The growth of the strength of electric field lead to an increase of $T_e$. As Fig. 5 and 6 shown, $T_e$ is within the range of 5~10 eV, the ionization rate of $H_2O$ is slightly smaller than that of $O_2$, while the attachment rate of $H_2O$ is much larger than that of $O_2$. As the ratio of $H_2O$ increases, the effective ionization rate will decrease. Therefore, after 8 ns, the density of electrons decreases with the increase of ratio of $H_2O$. Accordingly, the development of streamer at air-dielectric interface is more hardly with the increase of ratio of $H_2O$, and threshold of breakdown improves, which is in a good accordance with the experimental data [7].

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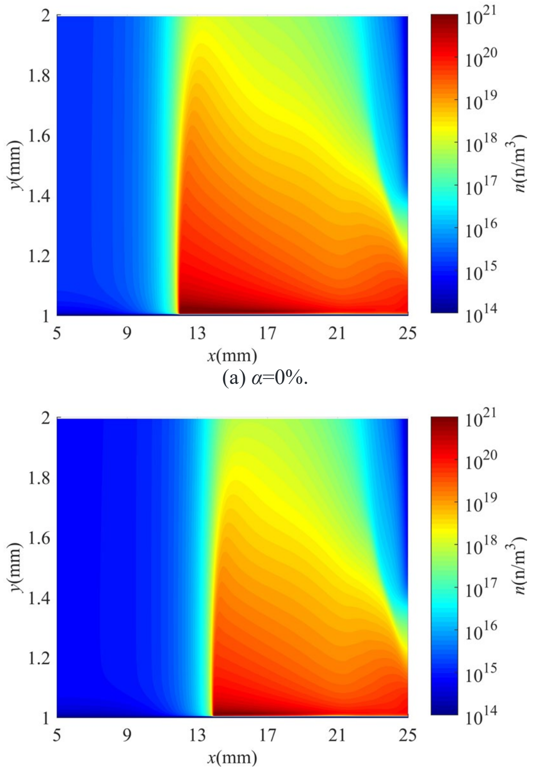
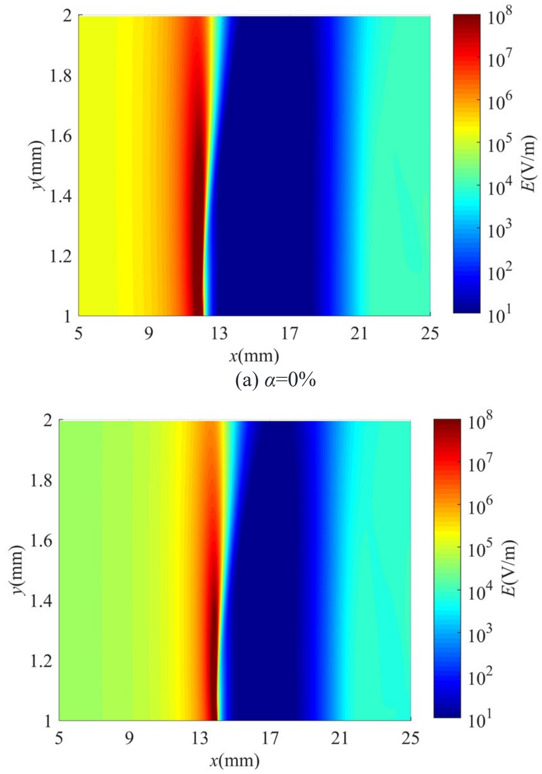



(a) $\alpha$=0%.

(b) $\alpha$=2%.

Fig.7 Distribution of density space charge with (a) the ratio of $H_2O$ $\alpha$=0% and (b) the ratio of $H_2O$ $\alpha$=2% when $t$ = 12 ns.




(a) $\alpha$=0%

(b) $\alpha$=2%

Fig.8 Distribution of strength of electric field with (a) the ratio of $H_2O$ $\alpha$=0% and (b) the ratio of $H_2O$ $\alpha$=0% when $t$ = 12 ns.

## IV. Conclusion

In summary, the effect of humidity on air-dielectric interface breakdown under the nanosecond pulses under uniform electric field is studied. A flat electrode model is used to simulate the discharge. The spatial evolution of electric field and particles have been obtained. The results indicate that the threshold of breakdown at air-dielectric interface increases with the increase of ratio of $H_2O$. A theoretical analysis of the discharge process is conducted. The results show that compared to $O_2$, $H_2O$ has a higher attachment rate when $T_e$ is around 5~10 eV, but a lower ionization rate. The effective ionization rate decreases with an increase of $H_2O$ ratio. Therefore, surface flashover breakdown is more difficultly to occur in the humid air, which is consistent with the experimental data. These findings provide a basis for a deeper understanding of the breakdown mechanism at the air-dielectric interface.

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