COMPARATIVE INVESTIGATION OF CREEPING DISCHARGE CHARACTERISTICS AT WAVEFRONT OF PULSE VOLTAGE IN SF_6/N_2 AND CO_2/N_2 GAS MIXTURES

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ABSTRACT

Creeping discharge characteristics in N_2, SF_6 and CO_2 have been investigated under single pulse voltage application. Anomalous behaviour in creeping flashover voltage has been found in SF_6/N_2 and CO_2/N_2 mixtures. In SF_6/N_2, reduction of flashover voltage has been induced by small amount SF_6 admixture in N_2 not only for negative but also for positive by increase of front steepness of applied pulse. On the other hand, in CO_2/N_2 maximum value of flashover voltage has been observed for about 10~30%-CO_2 admixture into N_2. These anomalous phenomena should be associated with creeping corona development process and charge accumulation on dielectric barrier surface.

1. INTRODUCTION

SF_6 gas has excellent insulating properties, and it has contributed to the high performance of the electric power apparatuses. However, a significant decrease of dielectric strength is induced under a non-uniform electric field by the existence of a protrusion or a metallic impurity, or by invasion of a steep front surge. Moreover, leakage of SF_6 is regulated due to the high global warming ability compared with that of CO_2 [1].

N_2, CO_2 and their mixtures as well as SF_6/N_2 mixtures have been interested in the practical application as an insulating medium in place of SF_6 [2,3]. However, the insulation characteristics of those gases under the non-uniform field have not been clarified. Especially, creeping flashover characteristics have not been elucidated.

In our previous work, we reported creeping flashover characteristics in SF_6/N_2 mixtures in detail [4-6]. We have found that the negative creeping flashover voltage in N_2 (D=0%) is as high as that of SF_6 (D=100%), and the remarkable reduction of flashover voltage is induced by the small SF_6 gas mixture, and the flashover voltage has unique V-t characteristics. And we proposed the mechanism of reduction of flashover voltage induced by small SF_6 addition.

To understand such uniqueness on flashover characteristics in SF_6/N_2 gas mixtures in detail and creeping flashover characteristics in other candidates, in this work, comparative study of creeping discharge characteristics in SF_6/N_2 and CO_2/N_2 mixtures under steep-front pulse voltage on non-uniform field have been investigated.

2. EXPERIMENTAL DETAILS

Electrode configuration is shown in Fig.1. A borosilicate glass plate as dielectrics was used. A needle electrode with a 35 μm-tip of curvature was arranged on it and the counter plane electrode was arranged at its edge. The distance between the needle and the plane electrode was fixed at l=7 mm. A thin rod was used as a backing electrode. This electrode system was set up in a container made of brass filled with gas mixture at 0.3 MPa.

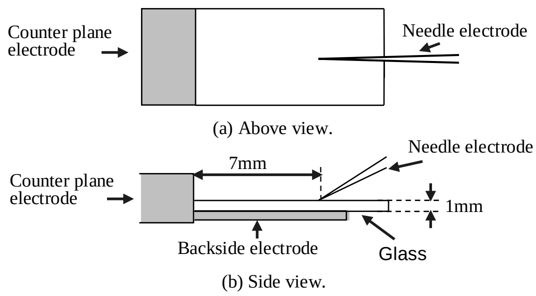


Fig. 1 Electrode configuration.

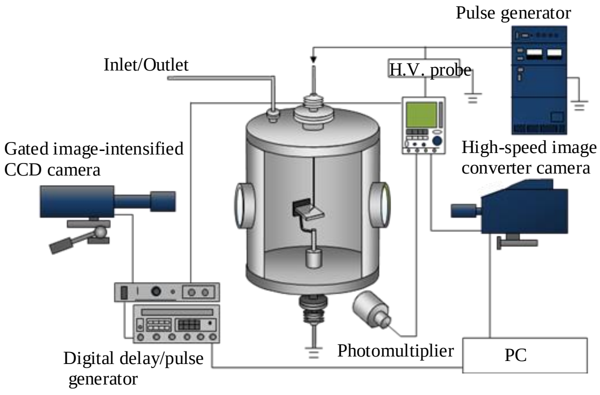


Fig. 2 Experimental setup.

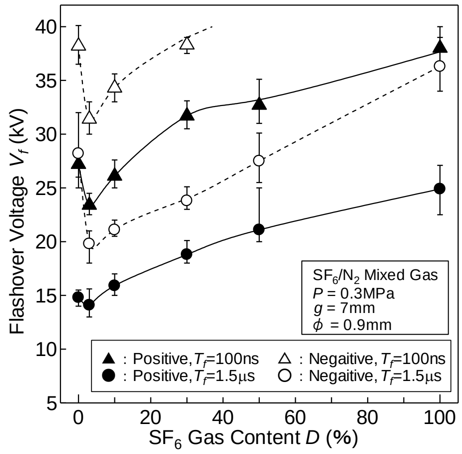


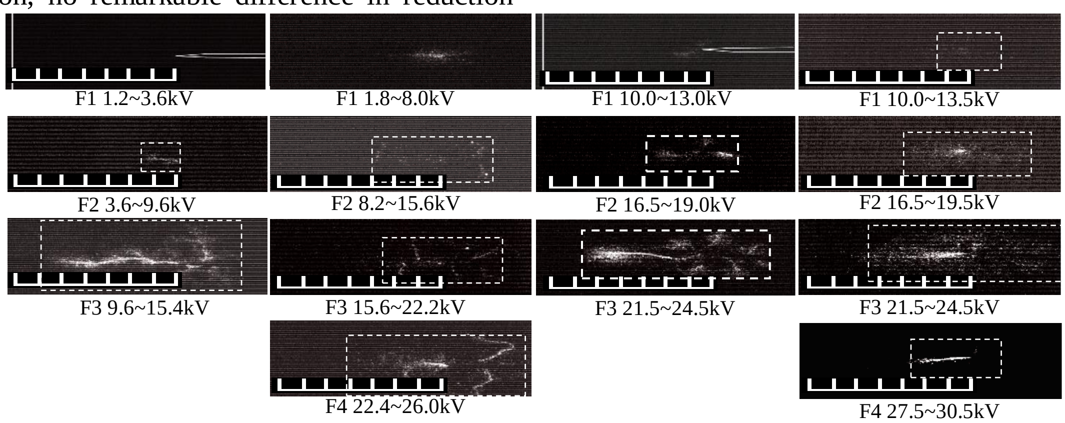
Fig.3 SF_6 gas content dependence of flashover voltage.

Figure 2 indicates experimental setup. A single pulse voltage with a front time duration of T_f=100 ns ~ 1.5 µs was applied between the upper needle electrode and the counter plane electrode. Corona onset voltage and flashover voltage were taken as instantaneous values at the first detection of corona emission and flashover on the wave front. Corona extension and creeping discharge development were captured using a high-speed digital framing camera and a CCD camera with high-speed gated image-intensifier.

3. RESULTS AND DISCUSSION

Figure 3 shows SF_6 content dependence of flashover voltage for a single pulse voltage with a front time duration of T_f=100 ns and 1.5 µs. In the case of negative polarity, the flashover voltage was higher than that in the case of positive polarity as well-known, furthermore remarkable reduction of flashover voltage by small SF_6 admixture was also observed as was reported in our previous work. A similar behaviour was obtained for O_2, which is also strong electronegative gas as well SF_6. In addition, no remarkable difference in reduction of flashover voltage was not appeared by increasing wave front steepness. In the case of positive polarity, the reduction in flashover voltage induced by small SF_6 mixture was not so markedly observed for T_f= 1.5 µs, but it was enhanced by reduction of wave front steepness to T_f=100ns. Reduction of flashover voltage has been clearly induced by small amount SF_6 admixture in N_2 not only for negative but also for positive by increase of front steepness of applied pulse. From the investigation of voltage – time characteristics, decrease of flashover voltage becomes large by reduction of wave front duration. It may suggest that discharge formative time lag and/or creeping discharge behavior are related with such unique phenomena on SF_6 content dependence of flashover voltage.

Figure 4 show extension behavior in the negative polarity in which condition the reduction of flashover voltage induced by small SF_6 addition is observed. From observation of corona extension, corona extension was suppressed relatively in N_2 (D=0%). It is considered that creeping discharge characteristics in N_2 are unique, which may associated with field



(a)T_f=1.5µs, D=0% (b)T_f=1.5µs, D=0% (c)T_f=100ns, D=3% (d)T_f=100ns, D=3%

Fig.4 Creeping corona extension in SF_6/N_2 by high speed camera (Negative) relaxation induced by accumulated charges on the barrier. On the contrary, corona extension behavior in 3% is greatly different from that in N_2. Namely, impulsive corona development is observed by 3%-SF_6 addition, which is typical behavior in SF_6 under the non-uniform field. This fact suggests that the unique creeping flashover characteristics caused by accumulated charge distribution and charge density on the barrier depending on SF_6 content.

Broad corona light emission, strong emission on the barrier surface and its suppression were appeared on the corona extension observation in N_2 (D=0%). This fact interpreted as follows. Charges generated by ionization near the needle tip are accumulated on the barrier surface with increasing applied voltage. Corona extension is suppressed tentatively by the field relaxation induced by those accumulated charge. However, impulsive corona emission increases by small SF_6 addition, leading to repetition of corona extension and suppression on the barrier in short periods. Furthermore, creeping corona gradually develops along the backside electrode without any suppression by small SF_6 addition.

Electron attachment coefficient for electrons with energy of 2 eV is 3～4 order of magnitude lower than that for electron with energy of 1eV. By admixture of SF_6 into N_2, negative ions are generated by attachment of low energy electrons induced by collision with N_2 molecule near the needle tip. Therefore, the field relaxation effect by the accumulated charge on the barrier is reduced, leading to easy creeping corona development. In addition, photo-ionization is effective at low SF_6 content. It means that electron supply increases and corona development is enhanced. In the case of further SF_6 content, electron attachment effect of SF_6 molecules is essentially dominant, so that creeping flashover voltage in SF_6 (D=100%) is higher than that in N_2 (D=0%). The above-mentioned process results in reduction of flashover voltage by small SF_6 addition.

It is well-known that CO_2 gas is also electronegative gas, but its electronegativity is weak. We have investigated that creeping discharge characteristics in CO_2/N_2 in comparison with that in SF_6/N_2. Figure 5 indicates CO_2 content dependence of creeping flashover voltage. On the other hand, in the case of CO_2/N_2 mixed gas, the dependency of gas content on flashover voltage is quite different from that in the case of SF_6/N_2, a maximum value of flashover voltage has been observed for 10 to 30% CO_2 admixture into N_2. This behaviour is not so remarkable in the positive polarity, but in the negative polarity it is clearly observed, especially for T_f= 1.5 µs. This type of dependency is reported only limited gas mixture under uniform field.

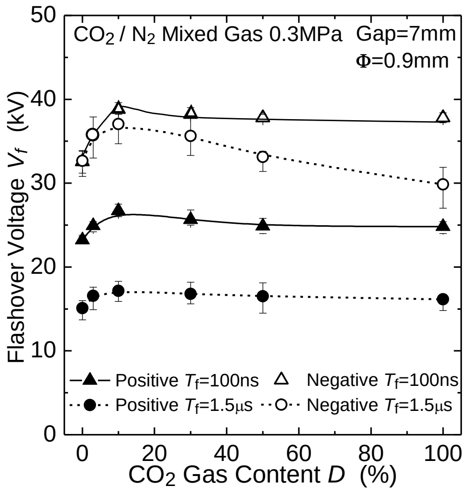


Fig. 5 CO_2 gas content dependence of flashover voltage.

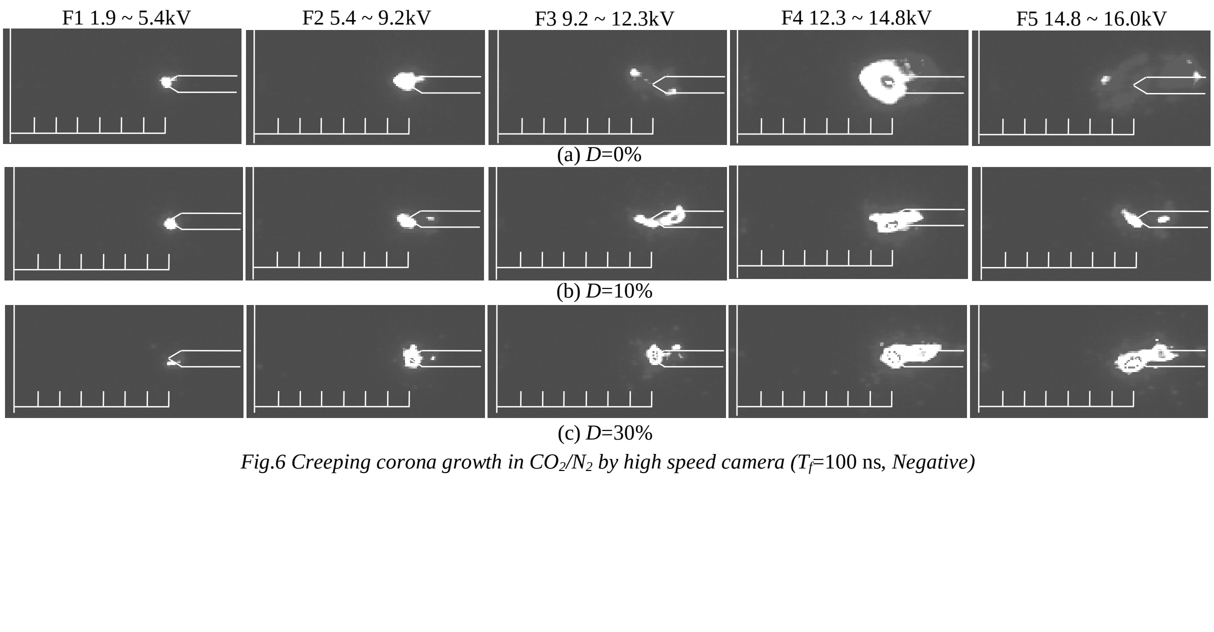


Fig.6 Creeping corona growth in CO_2/N_2 by high speed camera (T_f=100 ns, Negative)

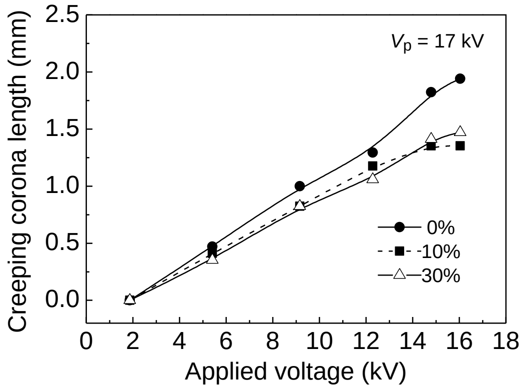


Fig.7 Applied voltage dependence of creeping corona growth

Figure 6 shows images of creeping corona growth at the early stage for T_f= 100 ns using image intensified high-speed camera. And the relationship between creeping corona growth length and applied voltage is shown in Fig.7. As is evident from these results, the corona growth at early stage is suppressed for CO_2 mixtures of D=10 and 30% compared with that for pure N_2 D= 0%. Similar behaviour is observed for T_f= 1.5μs.

Creeping corona development image until flashover in CO_2/N_2 mixtures is shown in Fig.8 for T_f= 1.5 μs. In D=30%, broad corona emission is appeared widely on the solid dielectrics just like observed in pure N_2 (D=0%). On the contrary, in pure CO_2 (D=100%), creeping corona extension is relatively suppressed due to the electron attachment. From these corona extension behaviour and anomalous phenomena on the creeping flashover voltage which indicates maximum at around D=10~30% should be associated with creeping corona progress on dielectric surface affected by accumulated charge and electron supply from dielectrics.

4. CONCLUSION

Creeping discharge characteristics at wave front of pulse voltage in N_2, SF_6 and CO_2 have been investigated. Anomalous behaviour in creeping flashover voltage has been found both in SF_6/N_2 and in CO_2/N_2. Reduction of flashover voltage has been induced by small mixture of SF_6 in N_2. On the other hand, in CO_2/N_2 maximum value of flashover voltage has been observed for about 10~30%-CO_2 admixture into N_2. Though the behaviour is quite different between them, but these anomalous phenomena should be associated with creeping corona development process and charge accumulation on dielectric barrier surface for both cases.

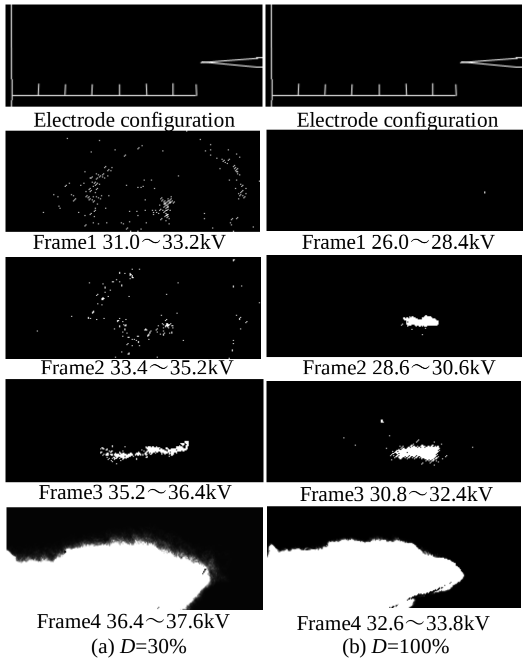


Fig.8 Creeping corona extension in CO_2/N_2 (T_f= 1.5μs, Negative)

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