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Breakdown Characteristics Of SF_6/N_2 In Slightly Non-uniform Electric Field At Low Temperature

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Abstract: Since SF_6 has high liquefaction temperature, the reliability of GIS, GIL and other gas insulated electrical equipment is reduced, and the maintenance cost is high in areas with high latitude. Therefore, applying mixed gas of SF_6 and N_2 as an insulating medium can reduce the liquefaction temperature of the medium under the precondition of maintaining certain insulation strength. In the paper, a breakdown experimental platform was built to study the insulating property of SF_6/N_2 at low temperature. A slightly non-uniform electric field was generated by a hemisphere-plate electrode. The breakdown voltage of SF_6/N_2 with different mixing proportions at different gas pressures under low temperature condition was measured, therefore the influence law of temperature on mixed gas breakdown voltage was analyzed. The result showed that the insulating property of unliquefied mixed gas was not affected by temperature greatly in the slightly non-uniform electric field. The result in the paper has certain reference significance for applying SF_6/N_2 in GIS and other electrical equipment of high latitude areas.

1. Introduction

SF_6, as an electronegative gas with high insulating power, is widely used in GIS, GIL and other electrical equipment for insulation. However, SF_6 has high molecular mass, which can be easily liquefied at high pressure and low temperature, and the insulating property thereof will be reduced as a result. The temperature of North China is low in winter, and the lowest temperature can reach -35°C sometimes, thereby liquefying high pressure SF_6 and challenging the reliability of the electrical equipment[1]. SF_6 can be mixed with N_2, and the liquefaction temperature can be reduced under the precondition of maintaining excellent insulating property since mixed gas has synergism. Gas insulated electrical equipments with SF_6/N_2 as insulating medium can meet the requirements of low temperature operation environment in high latitude areas. As a result, the mixed gas becomes a hot research topic of SF_6 alternative gas as a result.

Boltzmann equation calculation[2], experiment and simulation, etc.[3] are adopted frequently for analyzing discharge parameters, breakdown characteristics, discharge breakdown products, etc. of SF_6/N_2 in existing studies on insulating property. The change law of the insulating property under different electric field distributions, gas pressures, gas mixture ratios, power supply motivation types and other discharge conditions[4]-[6] are further studied. However, the insulating property is studied mostly at room temperature, and the property of mixed gas at low temperature is rarely studied[7], though it is of great guidance significance to study the insulation characteristics of SF_6/N_2 at low temperature for application of GIS and other gas-insulated equipment in cold areas.

In the paper, temperature can be adjusted between 0 and -15 °C at the breakdown experimental platform which was built in the paper. A slightly non-uniform electric field was generated by a hemisphere-plate electrode. Negative DC high voltage excitation was applied. The gas pressure range was between 15 and 60kPa. The breakdown voltage of SF_6/N_2 with different mixing proportions of 0/100, 25/75, 50/50 and 75/25 was measured. The influence of low temperature environment on breakdown characteristics of SF_6/N_2 was analyzed.

2. Experiment Design and Method

A breakdown experimental platform was built as shown in Fig. 1 to simulate the breakdown environment of insulating medium in GIS. The experimental platform was mainly composed of a gas distribution system, a discharge chamber and a low temperature generation and measurement system.

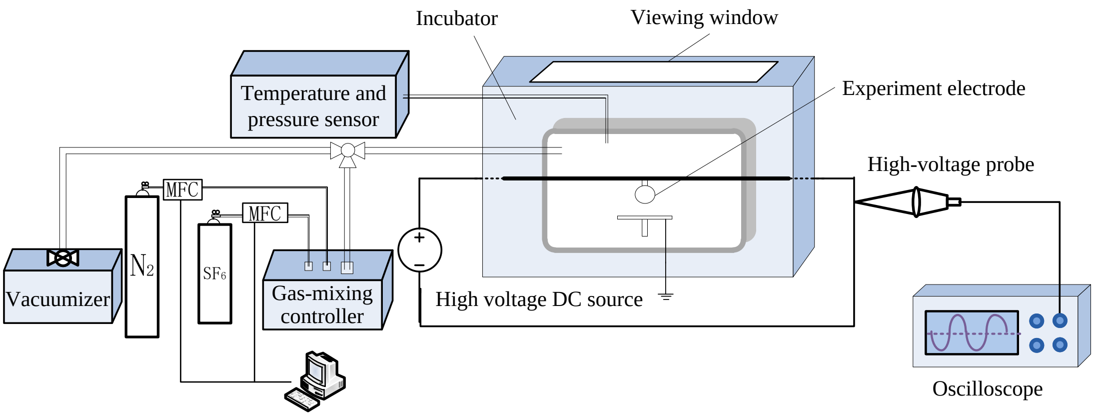


Figure 1 Diagram of devices for breakdown experiment.

Insulating medium disruptive discharge sometimes occurred between metal particles and metal plane in GIS. To simulate the discharge structure, a slightly non-uniform electric field was generated by a hemisphere-plate electrode wherein Rogowski electrode[8] was adopted as the plate electrode to eliminate the edge effect of the plate electrode. The electrode structure diagram was shown in Fig. 2. It was calculated according to the statistics formula of electric field non-uniformity factor [9] that the electric field non-uniformity factor generated by the hemisphere-plate electrode was f=1.1050 when electrode spacing was 6mm, and it belonged to a slightly non-uniform electric field.

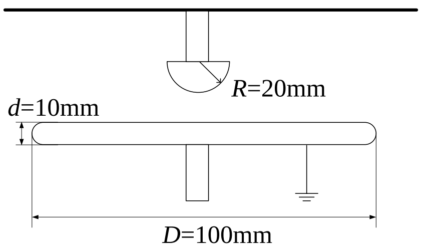


Figure 2 Design of electrode for experiment.

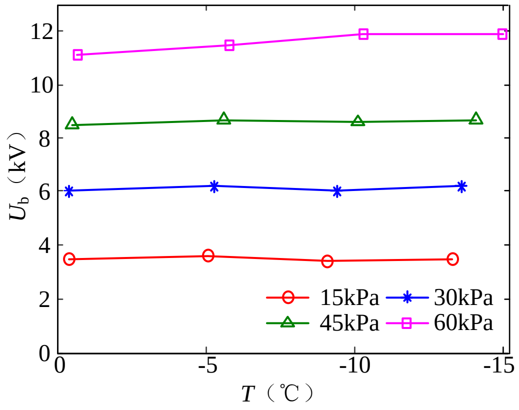
DC high-voltage power supply was adopted as discharge excitation to analyze the breakdown characteristic of SF_6/N_2 intuitively, and reduce the random error in the limited breakdown discharge. According to DC breakdown test method in 'High Voltage Experimental Technique'[10], voltage was applied until obvious breakdown occurred in the electrode gap, and breakdown voltage was measured.

In the experiment, low temperature nitrogen volatilized from liquid nitrogen was utilized for cooling the discharge chamber, and the low temperature scope was selected between 0 and -15°C to fully guarantee the stability of temperature.

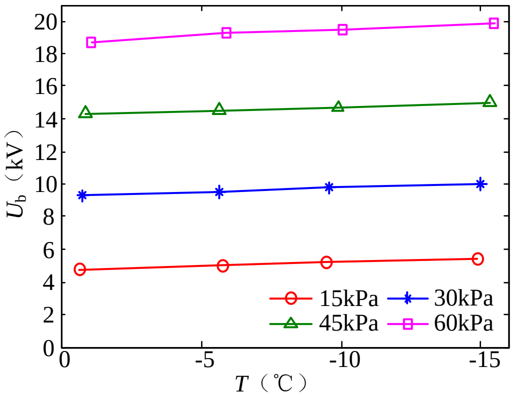
3. Experimental Results and Analysis

3.1. The breakdown Voltage at Low Temperature

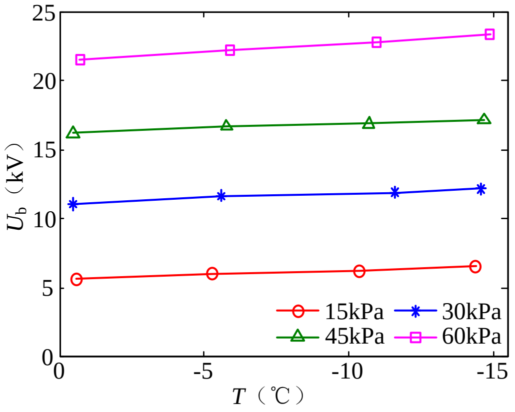
The SF_6/N_2 breakdown voltage under different working conditions in the slightly non-uniform electric field is shown as Fig. 3, wherein the electric field was generated by the hemisphere-plate electrode. Data in the figure showed that the breakdown voltage of gases with different mixing proportions was slightly increased with the reduction of temperature aiming at overall change trend. Moreover, the amplitude of variation was very small. The breakdown voltage was only changed by 10% or so during temperature decrease from 0 °C to -15 °C. The influence of temperature on breakdown voltage was not changed with the SF_6 content in the mixed gas aiming at gases with different mixing proportions.



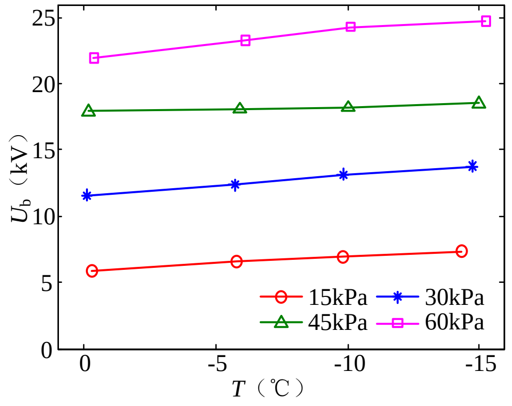
a) SF_6/N_2:0/100



b) SF_6/N_2:25/75



c) SF_6/N_2:50/50



d) SF_6/N_2:75/25

Figure 3 Breakdown voltage of SF_6/N_2 mixed gas in the slightly non-uniform electric field.

As a whole, the breakdown characteristics of SF_6/N_2 in the temperature and pressure range was affected by temperature slightly. The main reason was that mixed gas was not liquefied, and the molecular density of the medium was hardly changed at the temperature and gas pressure. Low temperature affected the breakdown process mainly through gas particle collision, Brownian motion and other microscopic process. The energy loss was increased during particle movement and collision, and the kinetic energy of particles was reduced. Therefore, the ionization was weakened, and attachment was enhanced during collision[11]-[12]. As a result, the discharge process was developed slowly, and the breakdown voltage was increased. However, since the microscopic process was affected by temperature in the scope slightly, the breakdown voltage was not affected by temperature in the scope that mixed gas was not liquefied. In addition, the relative distance among curves in the figure showed that the mixed gas was affected by pressure more prominently compared with temperature. So, when temperature and pressure were fluctuated in the corresponding scope, the pressure played a more critical role to insulating property of mixed gas.

The law curve in the figure showed that the breakdown voltage of SF_6/N_2 was related with temperature and pressure linearly. Therefore, the breakdown voltage obtained from the experiments of SF_6/N_2 in different gas mixing proportions can be fit by a polynomial method. Corresponding linear fitting formula and goodness of fit were obtained as shown in Table 1.

Table 1 Breakdown voltage fitting formula of mixed gas under slightly non-uniform electric field.

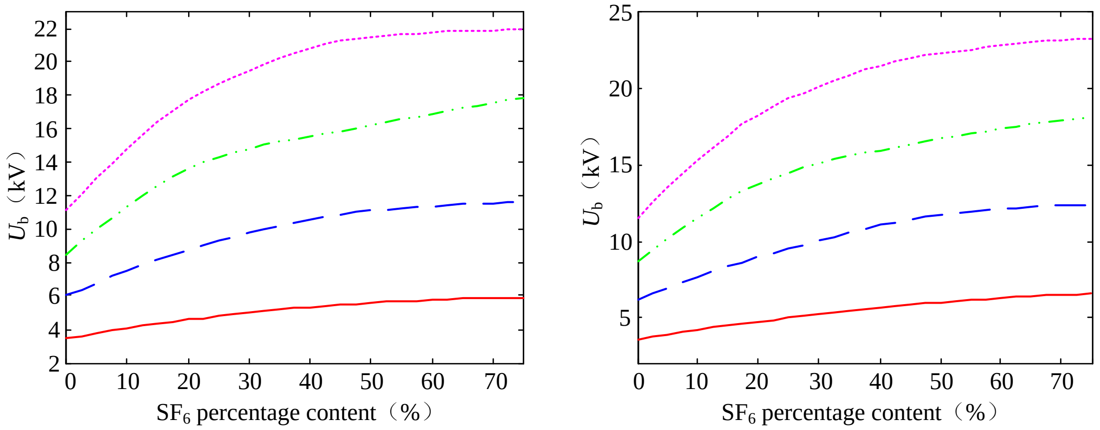
Mixed gas proportion (SF_6/N_2)	Fitting formula	Goodness of fit
0/100	U_b=0.613+0.178p-0.021T	0.9962
25/75	U_b=-0.147+0.317p-0.054T	0.9995
50/50	U_b=0.060+0.361p-0.082T	0.9986
75/25	U_b=0.426+0.371p-0.124T	0.9962

Wherein, U_b-- breakdown voltage of mixed gas, kV;
p -- pressure of mixed gas, kPa;
T -- temperature of mixed gas, °C.

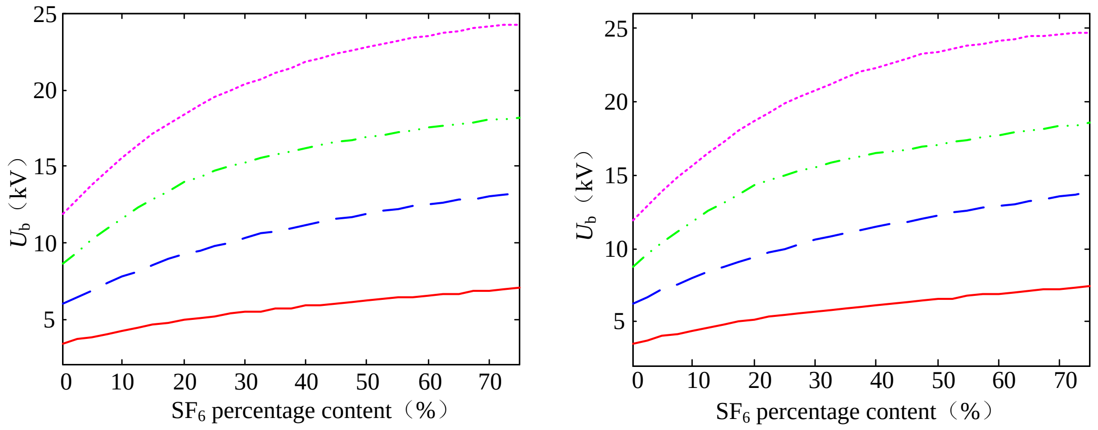
Data in the table showed that the goodness of fit of mixed gas breakdown voltage fitting formulas was higher than 0.99, which indicated that the formula had excellent fitting effect. The fitting formula in the table showed that the temperature coefficient was negative in the formulas of breakdown voltage U_b, wherein the gas was mixed according to four different mixing proportions. It showed that the breakdown voltage of the mixed gas was increased with temperature decrease. The absolute values of coefficients were respectively 0.021, 0.054, 0.082 and 0.124 under four different mixing proportions. Namely, the SF_6/N_2 breakdown voltage was slightly affected by temperature. However, the SF_6 content was more in the mixed gas, the temperature sensitivity was higher slightly. On the other hand, the pressure coefficient was higher than zero, so the breakdown voltage was further increased with the pressure increase of mixed gas. The coefficient was respectively 0.178, 0.317, 0.361 and 0.371 under four different mixing proportions, increased with increase of SF6 content in the mixed gas. It was obvious that the mixed gas contained more SF_6 , the breakdown voltage increase amplitude was higher under the same gas pressure change. The phenomenon was beneficial for improving the insulating property.

3.2. Change Law of SF_6/N_2 Breakdown Voltage with SF_6 Content at Low Temperature

The measured results were expressed as the curve that the breakdown voltage was changed with SF_6 percentage content, and it was shown in Fig. 4.



a) T= 0 °C b) T= -5°C



c) T= -10°C　　d) T= -15°C

Figure 4 Change law of mixed gas breakdown voltage with SF_6 percentage content.

Each curve chart showed that the breakdown voltage was not increased linearly with gradual increase of SF_6 percentage content in the mixed gas. It was increased more prominently when SF_6 was a little. The breakdown voltage was increased more and more slowly and tended to be saturated with gradual increase of SF_6 content. In addition, the insulating property of SF_6/N_2 containing 20%~30% SF_6 reached 80% or so of the mixed gas containing 75% SF_6. The change law was not changed prominently with temperature decrease.

4. Conclusion

An SF_6/N_2 breakdown experimental platform within the temperature range of 0°C ~-15°C is built in the paper. The breakdown voltage of SF_6/N_2 with different mixing proportions and gas pressures in the slightly non-uniform electric field is measured. The following conclusions are obtained:

(1) The insulating property of the SF_6/N_2 is affected slightly by temperature. The influence is not changed with SF6 content change in the gas when the mixed gas is not liquefied;

(2) The influence of gas pressure on the insulating property is more significant than the influence of temperature at low pressure when mixed gas is not liquefied.

(3) The enhancement of SF_6/N_2 insulating property is reduced gradually with the increase of SF_6 proportion in the mixed gas, and the enhancement process is gentler and gentler. The change law is almost not affected by temperature.

(4) When the plan of applying SF_6/N_2 in low temperature environment is formulated, it is not necessary to consider the influence of temperature on the performance of insulating medium under the precondition of ensuring no liquefaction of the mixed gas.

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