Influence of Oxygen on Characteristic Law of $C_5F_{10}O/N_2$ Mixture Partial Discharge Statistical Characteristic

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Abstract In recent years, $C_5F_{10}O$ (Perfluoro(3-methyl-2-butanone), as a potential substitute gas for SF_6, has attracted extensive attention from researchers. $C_5F_{10}O$ has high molecular freedom and strong energy absorption ability. Due to the high fluorine content in $C_5F_{10}O$ gas, it has excellent insulation characteristics, more than twice that of SF_6 under the same conditions. It is considered to be the most promising alternative gas for SF_6. $C_5F_{10}O$ mixed ratio insulating gas is a new type of environmentally friendly insulating gas, and its partial discharge statistical characteristics are rarely studied at home and abroad. In this paper, the statistical characteristics of partial discharge in $C_5F_{10}O/N_2$ gas mixtures under extremely inhomogeneous electric field conditions are studied, and the characteristics of their statistical characteristics are analyzed. It is found that the addition of oxygen changes the partial discharge decomposition characteristics of the $C_5F_{10}O/N_2$ gas mixture, degrades the partial discharge characteristics of the $C_5F_{10}O/N_2$ gas mixture, making the more severe the electron dissociation, and increases the electric field distortion near the needle tip, thereby promoting the discharge on both sides of the sinusoidal voltage peak (around 270°).

Keywords New environmental protection insulating gas · $C_5F_{10}O/N_2$ mixed gas · Partial discharge · Discharge statistical characteristics

1 Introduction

In the field of high voltage, the excellent insulation characteristics of SF_6 gas make it always occupy a leading position in the electrical field and power industry. Nearly 80% of the usage of SF_6 gas is used in the electrical field and power industry every

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year [1]. However, SF_6 also has the disadvantages of long atmospheric life and greatly aggravating the greenhouse effect [2]. The Kyoto Protocol and the Paris climate agreement all list SF_6 as a gas that needs to be limited [3]. In addition, the decomposition of SF_6 by discharge will produce toxic low fluoride substances that seriously threaten human health, such as SF_4 and S_2F_{10}. Therefore, it is particularly important to find new environmentally friendly insulating gases that can replace SF_6 in order to reduce the emission of SF_6 for the sustainable development of power industry and environment.

In recent years, $C_5F_{10}O$, as a potential alternative gas to SF_6, has attracted extensive attention of researchers. It has excellent dielectric properties and environmental protection characteristics [4]. $C_5F_{10}O$ has high degree of freedom and strong energy absorption capacity [5]. The high fluorine content in the molecule also makes its insulation performance extremely excellent, which is more than twice that of SF_6 under the same conditions. $C_5F_{10}O$ has stable chemical properties, the global warming potential (GWP) is about 1, and the atmospheric life is about 15 days. It is not destructive to the ozone layer. Compared with SF_6, the negative impact on the natural environment is greatly reduced. However, due to the high liquefaction temperature of $C_5F_{10}O$, the liquefaction temperature at one atmospheric pressure is about 26.5 °C [6], so it can not be used alone. It needs to be mixed with buffer gas with low liquefaction temperature to avoid liquefaction, and the selection and proportion of mixed background gas is a major topic. Mantilla J D, gariboldin studied the power frequency breakdown voltage of $C_5F_{10}O$ mixed with N_2 and CO_2, and found that N_2 and CO_2 as background gases have good effects [7, 8]. Therefore, this paper selects N_2, which is more abundant and common in nature, as the background gas of the mixed gas for experimental research.

As a new type of environment-friendly insulating gas, there is less research on the performance of $C_5F_{10}O$ at home and abroad, and less research on the appropriate proportion of $C_5F_{10}O$ in the mixed gas [9]. Therefore, this paper uses the needle plate electrode simulation equipment to operate in a slightly uneven electric field environment, carries out the partial discharge experiment of $C_5F_{10}O/N_2$ mixed gas by using the power frequency partial discharge experimental platform, and changes the proportion of $C_5F_{10}O$ in the mixed gas, Collect and measure the gas decomposition components after partial discharge to analyze their decomposition characteristics, so as to provide experimental basis for the environmental protection substitution of $C_5F_{10}O$ and N_2 mixed gas, and provide theoretical basis for the substitution of environmental protection insulating gas in high-voltage electrical equipment [10, 11] (Table 1).

Table 1 Comparison of the basic properties of $C_5F_{10}O$ with SF_6, N_2 and CO_2

Chemical formula	Dielectric strength relative to SF_6	Boiling point (°C)	GWP/100-years
SF_6	1	−64	23,500
$C_5F_{10}O$	2	24	1
N_2	0.32−0.37	−79	1
CO_2	0.34−0.43	−196	–

2 Methodology

2.1 Test Platform

The equivalent circuit diagram of the partial discharge testing platform in this article is shown in Fig. 1. The AC Pressure regulator has a range of 0−380 V, which is used to control the output voltage of the test transformer; The protective resistor R has a resistance value of 10kΩ, which plays a role in avoiding overcurrent and protecting the circuit [12]. The circuit model of high voltage power frequency experimental platform is shown in Fig. 1.

The experimental gas chamber is made of stainless steel and can withstand the pressure of 0−0.6 MPa [13]. In the partial discharge experiment, the needle plate electrode is used to simulate a slightly uneven electric field. The needle electrode is made of tungsten copper and the plate electrode is made of brass.

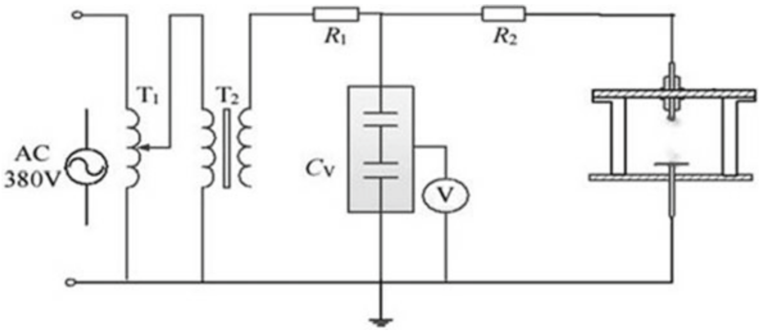


Fig. 1 Circuit of the AC partial discharge testing platform

3 Results

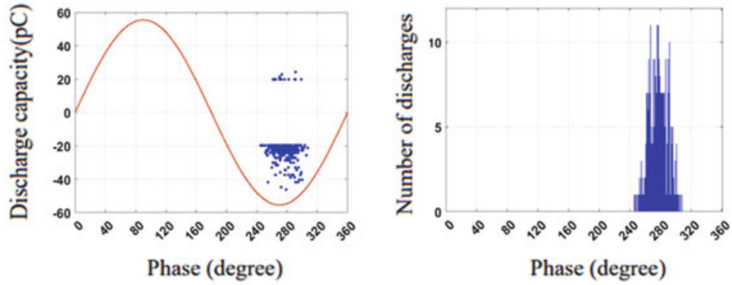
3.1 $C_5F_{10}O/N_2$ Gas Mixture PD Statistical Characteristics

In order to explore the characteristic law of the statistical characteristic quantity of partial discharge of $C_5F_{10}O/N_2$ gas mixture, this section uses software MATLAB to create a map reflecting the discharge quantity and discharge times. The following figure shows the PRPD map of partial discharge of $C_5F_{10}O/N_2$ gas mixture for 48 h under oxygen-free conditions. The left and right sides are respectively $C_5F_{10}O/N_2$ mixed gas, Q-φ (Discharge Phase) Graph and n-φ (Discharge times phase) atlas.

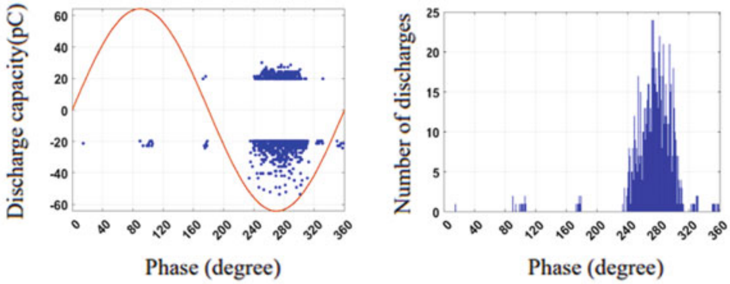
3.2 Discharge Quantity Phase Diagram and Discharge Frequency Phase Diagram

According to Fig. 2, the discharge times phase patterns at 12 h, 24 h, 36 h, and 48 h all conform to the Gaussian distribution characteristics. PD mostly occurs in the negative half cycle of power frequency, and the discharge amount and discharge times of the negative half cycle PD pulse at different times are much greater than the positive half cycle, indicating that the $C_5F_{10}O/N_2$ gas mixture has a polarity effect. The polarity effect is related to the space charge formed around the needle tip during the discharge process, that is, the ionization near the negative potential needle tip generates a large number of positive ions to form a space charge layer, and the direction of the space electric field is the same as that of the applied electric field, resulting in an increase in the intensity of the electric field near the needle tip, which is more prone to self- sustaining discharge and the generation of PD. Similarly, the positive polarity space charge near the electrode of the positive potential probe will weaken the field strength near the tip and inhibit the occurrence of PD. The peak value of the discharge frequency basically occurs at the phase of 270°, which is near the peak value of the sinusoidal voltage. Within 48 h, the discharge capacity basically maintained at around 50pC/pulse, while the discharge frequency showed a trend of increasing first and then decreasing, from 10 times in 12 h to 25 times in 24 h, then to 15 times in 36 h, and finally less than 10 times in 48 h. This is due to the fact that the experimental voltage remained at 24.5 kV, and the discharge amount remained basically unchanged without significant changes in the electrode plate and background gas. However, due to the continuous progress of partial discharge, the discharge frequency first increased with time, after a long time of partial discharge, the needle tip of the needle plate electrode will be ablated, and the needle tip will become increasingly bald after a long time of partial discharge, resulting in a decrease in the number of discharges.

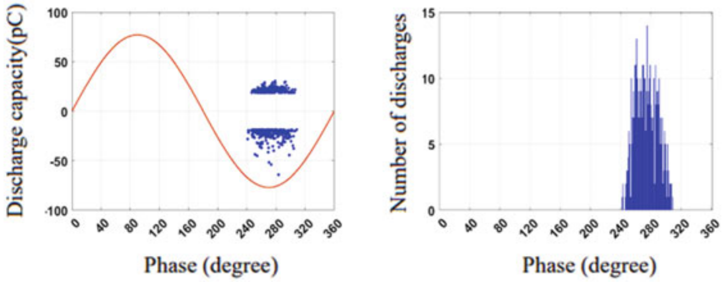
The following figure shows the statistical characteristic map of 48 h PD with an oxygen concentration of 8% (O_2 concentration of 24 kPa) and other conditions unchanged.



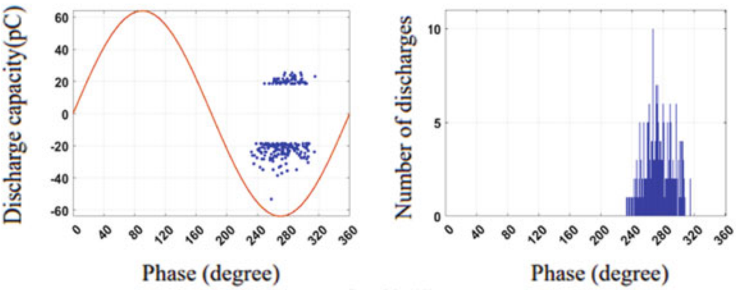
(a) 12h PD



(b) 24h PD



(c) 36h PD



(d) 48h PD

Fig. 2 PRPD spectrum of $C_5F_{10}O/N_2$ at 0.3 MPa

From Fig. 3, it can be seen that, unlike in the absence of oxygen, after adding 8% O_2, the discharge is more concentrated in the positive half cycle, that is, PD mostly occurs in the positive half cycle of the power frequency. And the PRPD pattern has different characteristics from that in the absence of oxygen. The discharge frequency phase diagram has changed from one peak to two main peaks, and the discharge frequency at the phase of 270° (at the peak of sinusoidal voltage) has greatly decreased. As shown in the figure, the maximum discharge frequency can reach 50 times at 230°, and the discharge quantity at the phase of 270° (at the peak of sinusoidal voltage) in the discharge frequency phase diagram is smaller than the discharge quantity on both sides.

The reason for this may be that the addition of oxygen changes the partial discharge decomposition characteristics of the $C_5F_{10}O/N_2$ gas mixture and degrades the PD characteristics of the $C_5F_{10}O/N_2$ gas mixture. From the perspective of gas discharge, due to the negative potential of the needle electrode, gas discharge causes electrons to dissociate, and the gas molecules collide with the free electrons emitted from the cathode to ionize. The ionized free electrons can continue to collide with the gas molecules to cause secondary electron avalanches, forming streamer channels. After the development of the streamer, there is a large and uniformly distributed space charge layer near the tip of the needle. The existence of the space charge layer weakens the front electric field near the tip, with a phase of 270° (at the peak of the sinusoidal voltage) having the strongest shielding effect on the tip, and with very small electric field distortion. However, due to the degradation of PD characteristics of $C_5F_{10}O/N_2$ gas mixtures by oxygen, the more serious the electron dissociation is, the greater the electric field distortion near the tip of the needle increases, thereby promoting discharge on both sides of the sinusoidal voltage peak (around 270°).

4 Conclusion

To sum up, using a power frequency high-voltage gas insulation test platform, the PD characteristics of $C_5F_{10}O$ under two different background gases, N_2 and CO_2, were systematically investigated, and the PD statistical characteristics of $C_5F_{10}O$ under two different background gases were analyzed theoretically. The following conclusions were obtained:

The addition of oxygen changes the partial discharge decomposition characteristics of the $C_5F_{10}O/N_2$ gas mixture, and degrades the PD characteristics of the $C_5F_{10}O/N_2$ gas mixture. The more severe the electron dissociation, the greater the distortion of the electric field near the needle tip, thereby promoting the discharge on both sides of the sinusoidal voltage peak (around 270°).

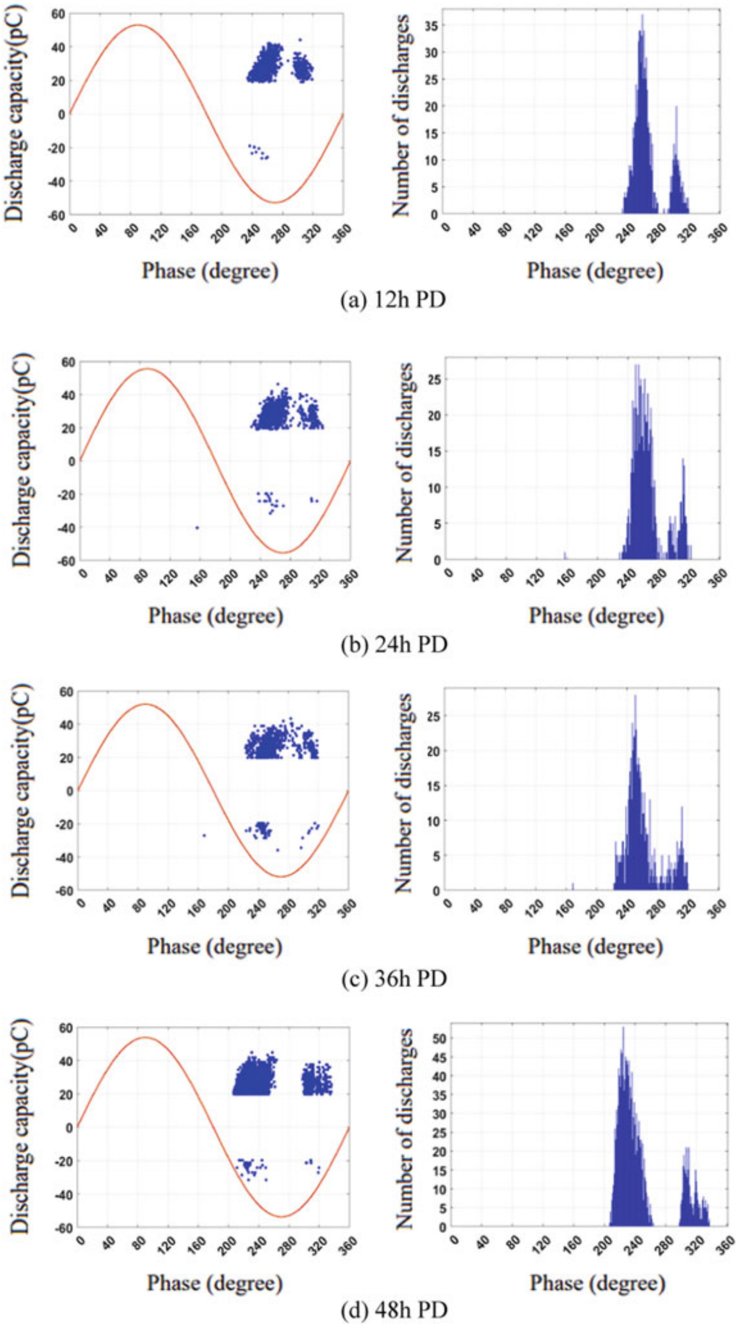


Fig. 3 PRPD spectrum of $C_5F_{10}O/N_2/O_2$ at 0.3 MPa

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