Circular Distribution of Corona Current of Multiple-Conductor Transmission Line (Ⅵ)

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The author investigates the corona starting voltages and the circular distribution of the corona current around a multiple-conductor transmission line in compressed SF_6, c-C_4F_8, C_2F_6 and N_2O gases.

The various characteristics of the d. c. corona current in fluoride gases mixed with N_2O and the results of the gaschromatographic analysis of the decomposition products by corona discharge are described.

1. Introduction

The authors have investigated the corona current distribution around the double-conductor and already published the five papers about the investigations.

The 1st, 2nd and 3rd papers1)~3) dealt with the various characteristics of the a.c. and d.c. corona current around the multiple-conductor transmission line in air. In the 4th and 5th papers,4)5) we described the corona starting voltages, the d.c. corona current distribution and the directivity characteristics around the double-conductor in N_2, CO_2, SF_6 and the organic fluoride gases like c-C_4F_8 and C_2F_6.

In this paper, the investigations about the various characteristics of the d. c. corona discharge in the fluoride gases like c-C_4F_8, C_2F_6 and SF_6 mixing with N_2O are carried out. And the results of the gaschromatographic analysis of the decomposed products are shown.

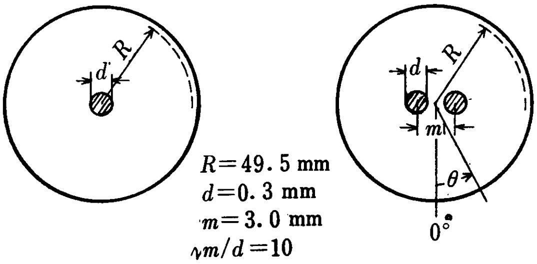
When the perfluorocarbons are exposed to the corona discharge or the arc discharge, they can easily be decomposed.6) And, on that account, carbon decomposed is accumulated on the electrodes. It is also reported that N_2O is available to prevent the carbon accumulation.

The authors investigate how the corona characteristics in perfluorocarbon are influenced by mixing with N_2O and, from the vewpoint of the electron attachment coefficient, the corona starting voltages in SF_6 mixing with N_2O are studied.

2. Experimental Equipments, Measuring Method and Definition of Directivity Factor κ

The experimental equipments in this paper are the same as those in the previuos,4)5) and so the details are omitted.

Fig. 1 shows the cross-section of the electrodes. Fig. 1 (a) is the case of single-conductor and Fig. 1 (b) the case of double-conductor, respectively.



(a) Single-Conductor (b) Double-Conductor

Fig. 1 Cross-Section of Electrodes

A X-Y Recorder was used for measuring the corona starting voltage. The total corona current I_t and the applied voltage V were recorded on the Y- and X-axes, respectively. The corona starting voltage is defined as the value corresponding to the abrupt increase point of I_t.

A X-T Recorder was used for measuring the distribution of the d.c. corona current. The terminal voltage-drop across the standard resistance means the magnitude of the corona current.

The authors define the directivity factor κ in order to analyse the corona current distribution quantitatively as shown in the previous papers;[4)5)] that is,

$$\text{Directivity Factor}\quad \kappa=\frac{I_{\max}}{I_{\min}}$$

$$=\frac{I_{90^\circ \text{ or } 270^\circ}}{I_{0^\circ \text{ or } 180^\circ}}\cdot \quad\cdots\cdots\cdots(1)$$

3. Corona Starting Voltages in Various Gases

Fig. 2(a) shows the corona starting voltages in air, SF_6, c-C_4F_8, C_2F_6 and N_2O around the single-conductor and Fig. 2(b) those around the double-conductor, respectively. The voltage-gradient of the corona starting at the surface of the conductors, E_s, is also shown on the ordinate axis. E_s, at the applied voltage of V(kV), is given as follows;

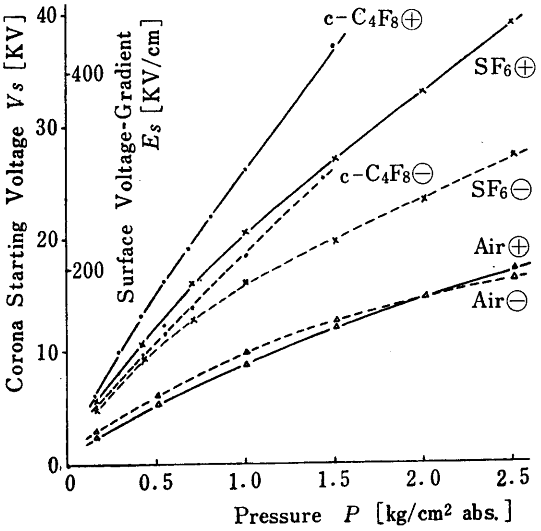
Single-Conductor·········

$$E_s=11.5\times V(\text{kV}) \quad\cdots\cdots(2)$$

Double-Conductor·········

$$E_s=8.49\times V(\text{kV}) \quad\cdots\cdots(3)$$

When the maximum voltage-gradient of the double-conductor is compared with that of the single-conductor, they are coincident within the limits of ±5 %. The corona starting voltage of the double-conductor increases 30~40 % in c-C_4F_8 and SF_6.



⊕ and ⊖ mean the potentials to be positive and negative, respectively.

Fig. 2(a) Corona Starting Voltages in Various Gases around Single-Conductor

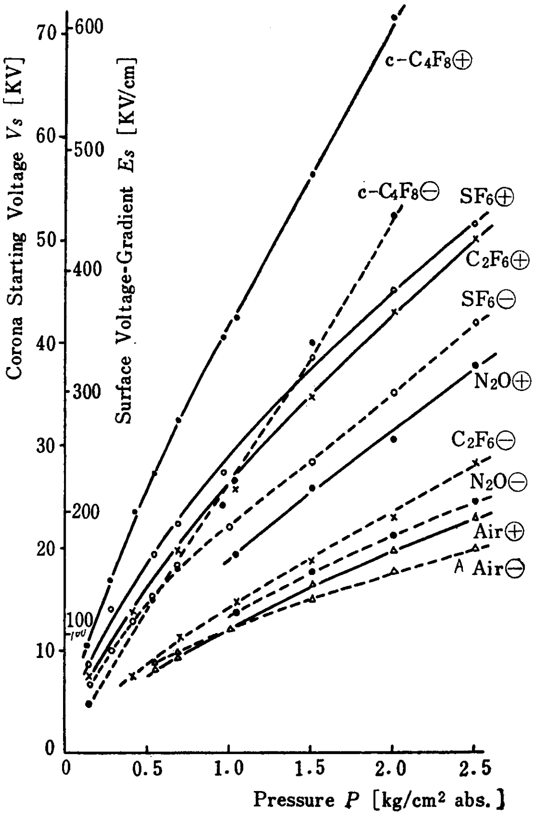


Fig. 2(b) Corona Starting Voltages in Various Gases around Double-Conductor, m/d =10

Fig. 2(b) shows the corona starting voltages (abbrev. V_s) around the double-conductor in various gases. V_s of c-C_4F_8 ⊕ is the highest of all the gases used in overall pressure. In less than 1 atm, however, V_s of c-C_4F_8 ⊖ is lower than that of SF_6 ⊕. The differences between positive and negative V_s is nearly constant in more than 1 atm in both case of c-C_4F_8 and SF_6. The difference in c-C_4F_8 is ca. 20 kV and in SF_6 ca. 10kV. V_s of C_2F_6⊕ is 2~4 kV lower than that of SF_6 ⊕ in overall pressure and V_s of C_2F_6 ⊖ is ca. 10 kV lower than that of SF_6 ⊖. So that, from the viewpoint of the electrical insulation, C_2F_6 is not so useful as c-C_4F_8. However, it has been advocated to mix C_2F_6 with c-C_4F_8 in order to lower the high boiling point of c-C_4F_8.

In Fig. 2(b), is also shown V_s of N_2O, which is mixed with perfluorocarbon or SF_6. V_s of N_2 ⊕ is 3~4 kV lower than that of SF_6⊖ in more than 1 atm. V_s of N_2O ⊖ is a little higher than that of air ⊕.

In Fig. 2(b), the characteristis curves of the corona starting voltages of single-conductor show the same tendency as those of double-conductor.

Table. I Calculation of the Constants A and C

A and C Gases Polarity	A		C	
	Positive	Negative	Positive	Negative
SF_6	67.58	76.89	0.3054	0.1422
c-C_4F_8	72.8	118.7	0.375	0.0898

Table. I shows the constants A and C when Watson's equation (4) is applied to c-C_4F_8 and SF_6. A and C are calculated in consideration of the two cases of r, that is $r=0.005$ cm and $r=0.015$ cm.

Watson's Equation

$$E_s=\mathrm{A}m_1\delta\left(1+\frac{\mathrm{C}}{\sqrt{\delta r}}\right)\ \cdots\cdots\cdots\cdots\cdots(4)$$

where

E_s : corona starting voltage-gradient in kV/cm

m_1 : coefficient of surface condition

δ : relative air density

r : radius of curvature of the conductor in cm

A&C : constants determined by the polarity and gases

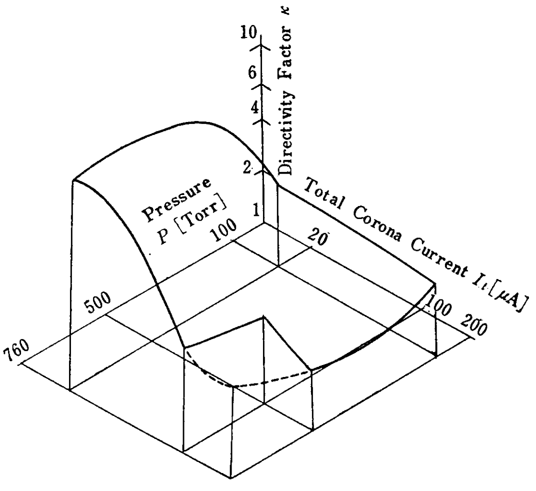
4. Directivity Characteristics in Various Gases

The authors have reported the directivity characteristics of SF_6, c-C_4F_8, CO_2 and N_2 in detail in the 5 th paper.[5] In this section we investigate the directivity characteristics of C_2F_6 (which is one of the perfluorocarbons, like c-C_4F_8) and N_2O.

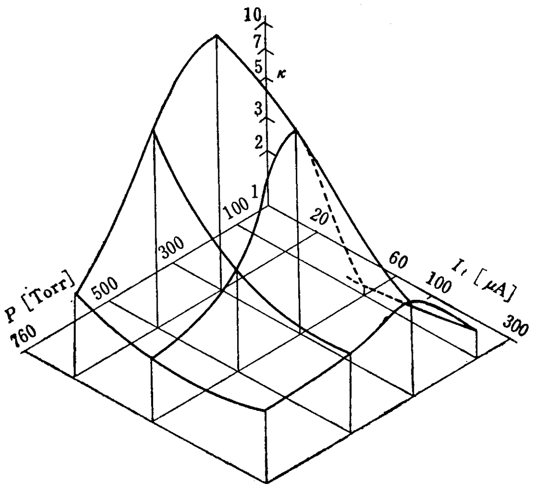
4-1. Directivity Factor in C_2F_6 Gas

Fig. 3 shows the directivity characteristics of C_2F_6. The κ-I_t characteristics of C_2F_6 cannot be always represented by the equation of $\kappa I_t^B=\mathrm{A}$, like in the case of c-C_4F_8.

In Fig.3 (a), the dependency of κ on pressure p in $C_2F_6\oplus$ is the smallest of all gases used and that of κ on the total corona current I_t in C_2F_6 is smaller than in c-C_4F_8. The directivity factor κ in the region of the lower pressure and the smaller corona current, could not be obtained because the distribution of the corona current was unstable.



(a) Positive Corona



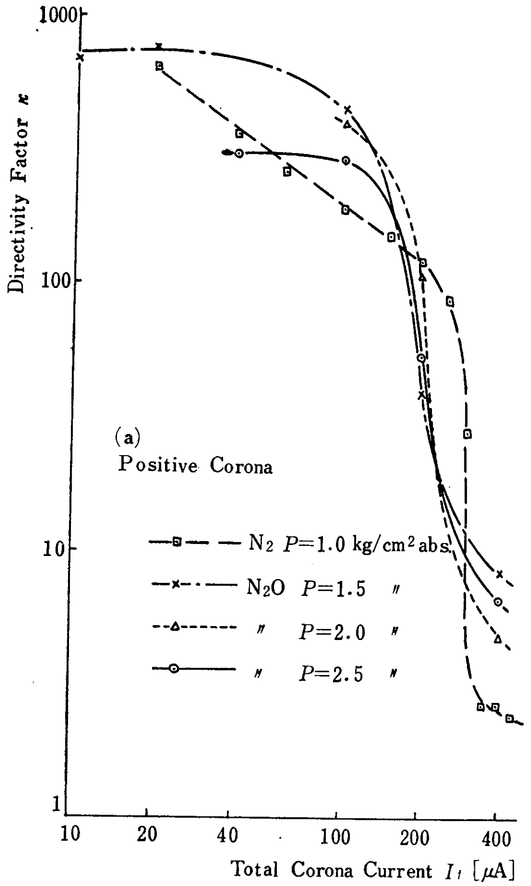
(b) Negative Corona

Fig. 3 Directivity Characteristics of Corona Current in C_2F_6

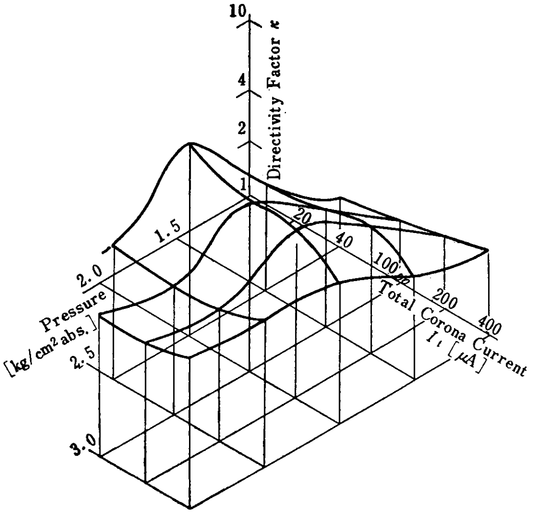
In Fig. 3 (b), κ of $C_2F_6\ominus$ has the different characteristics from that of $C_2F_6\oplus$. That is to say, the dependency of κ on pressure is small in the region of the large I_t and the maximum point of κ arises at $p=ca.$ 300 Torr in the region of the small I_t. These characteristics are the similar as observed in SF_6 $\ominus$[5].

4-2. Directivity Factor in N_2O Gas

Fig. 4 shows the directivity characteristics of N_2O. κ-I_t characteristics of the positive corona in N_2O are shown in Fig. 4 (a) and κ



(a) Positive Corona



(b) Negative Corona

Fig. 4 Directivity Characteristics of Corona Current in N_2O

of N_2 ⊕ is also shown. In this figure, κ-I_t characteristics of N_2O ⊕ are similar to those of N_2 ⊕. That is, κ-I_t characteristic curves in N_2 ⊕ at $p=1\mathrm{kg/cm^2}$ abs. are separated into two regions at I_t=ca. 300 μA.[4] Similarly, in N_2O there are two regions at ca. 200 μA.

On the contrary in the case of the negative corona, there are the differences between N_2 ⊖ and N_2O ⊖. κ in N_2 ⊖ could not be accurately obtained because of the unstable distribution of the corona current. In N_2O ⊖, however, the corona current distribution is stable and the κ-I_t-p characteristics are shown in Fig. 4 (b).

The differences of the distribution between N_2 ⊖ and N_2O ⊖ are explained by the existence of the electron attachment effect in electronegative gas (N_2O).

5. Corona Starting Voltages in Various Gases Mixing with N_2O

Fig. 5 shows the corona starting voltages V_s in various gases mixing with N_2O. The volume percentage of N_2O (abbrev. N_2Ov. %) is indicated on the quadrature axis. It is

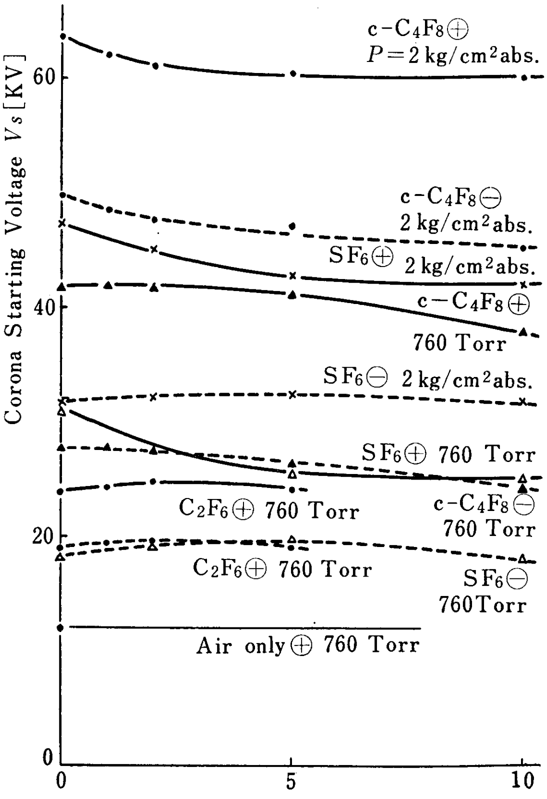


Fig. 5 Corona Starting Voltages in Various Gases Mixing with N_2O Gas

noted that V_s of $C_2F_6 \oplus$ mixing with N_2O increases a little (ca. 2 kV) at $p_{total}=760$ Torr when N_2O v. % is about 2 %. The same characteristics are observed in $C_2F_6 \ominus$. When N_2O is mixed with c-C_4F_8, V_s decreases gradually as increment of N_2O v. % and V_s at N_2O v. % = 10 % is ca. 4 kV lower than that of the pure c-C_4F_8.

It is worth considering to mix N_2O with perfluorocarbon in application to electrical insulation, because N_2O is effective to prevent carbon accumulation. It must be paid attention that N_2O gas is anesthetic and the chemical property of N_2O is similar to that of O_2.

In the characteristic curve of V_s in $SF_6 \ominus$ mixing with N_2O, the maximum point arises at N_2O v. % = 5~10 % at both $p=760$ Torr and 2 kg/cm^2 abs.

6. Directivity Characteristics in Various Gases Mixing with N_2O

Fig. 6 shows the comparison of the positive corona current distribution between c-C_4F_8 and c-C_4F_8 mixing with N_2O (percentage of mixing 95 : 5 % vol.) under the condition of $I_t=100\,\mu A$ and $p_{total}=760$ Torr. In Fig. 6, it is difficult to distinct the differences between both the corona current distribution. The corona current in the direction of $\theta=0°$ and 180°, if anything, increases a little in the mixed gas more than that in the pure gas.

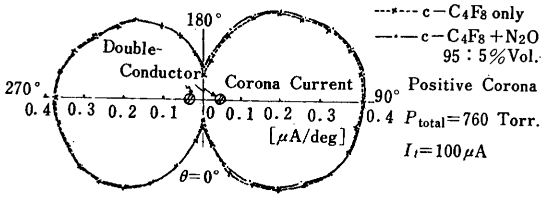
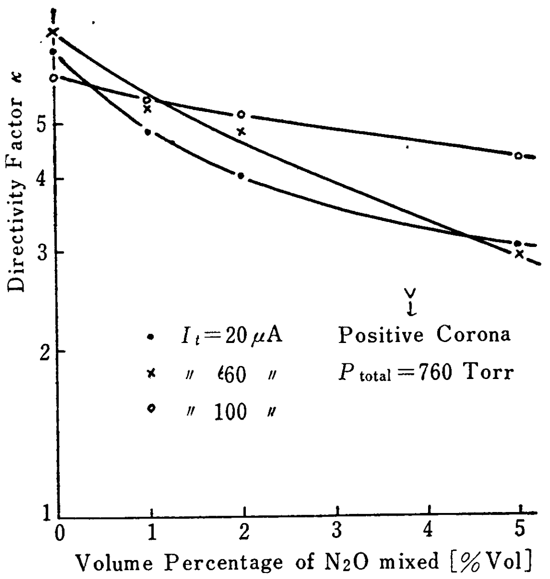


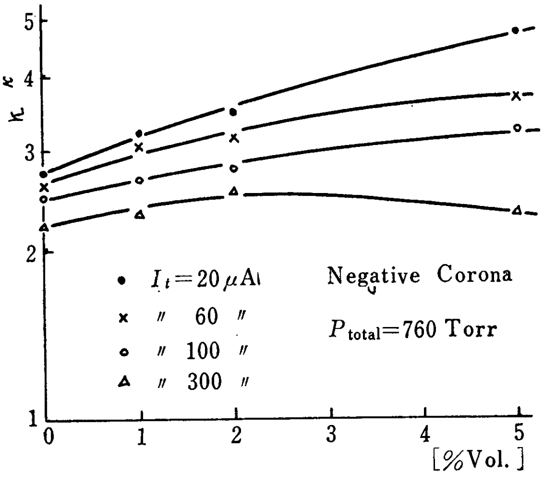
Fig. 6 An Example of Corona Current Distribution in c-C_4F_8 mixing with N_2O

Fig. 7 and Fig. 8 show the directivity characteristics in perfluorocarbon mixing with N_2O, 0~5 % vol. κ-axis is graduated in logarithms scale.

Fig. 7 (a) shows the directivity characteristics of the positive corona current distribution in c-C_4F_8 mixing with N_2O at $p_{total}=760$ Torr. κ tends to decrease as increment of N_2O v. %. On the contrary, as shown in Fig. 7 (b), κ of the negative corona characteristics increases as increment of N_2O v. %. The rate of the decrease (or increase) of κ gets small as I_t increases.



(a) Positive Corona



(b) Negative Corona

Fig. 7 Directivity Characteristics of Corona Current in c-C_4F_8 mixing with N_2O

Fig. 8 shows the directivity characteristics of the negative corona current distribution in C_2F_6 mixing with N_2O at $p_{total}=760$ Torr. In the κ-characteristic curve, a maximum point appears where N_2O v. % is ca. 2 %.

Even if N_2O is mixed with perfluorocarbon below ca. 5 %, the changes of the corona current distribution are not always large.

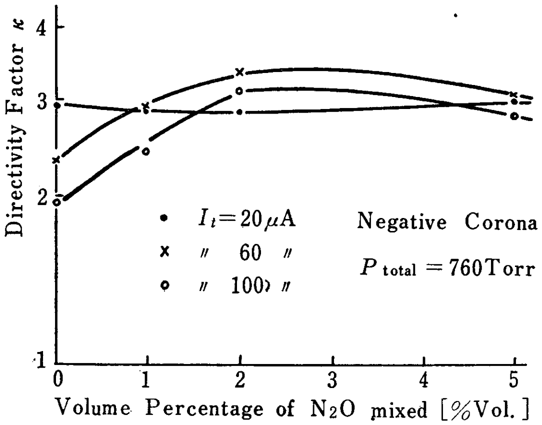


Fig. 8 Directivity Characteirstics of Corona Current in C_2F_6 mixing with N_2O

7. Gas Analysis of Decomposed Products in Perfluorocarbon Exposed to Corona Discharge

c-C_4F_8 at ordinary state is not toxic for human body and the thermal stability is very execellent[7], while are unknown the kinds and amounts of the products which are decomposed owing to the injection of electrical energy like corona discharge. The authors were confronted with the facts that c-C_4F_8 exposed to corona discharge would produce the decomposed poisonous materials. Therefore, we made an attempt to analyse c-C_4F_8 exposed to corona discharge by means of gaschromatograph.

The relation betweent the condition of the corona discharge, the kinds of the sampled gases and the purity are shown in Table. 2. This analysisis enough sufficient, because the rated purity of c-C_4F_8 is 99.5 %.

The important results of the gaschromatographic analysis are as follows;

(1) CF_3H was the most of all the decomposed products.

After corona discharge, CF_3H in sampled gas No. 1 increased 7500 times more than that in original gas and CF_3H in No.2 5100 times, respectively. The purity of CF_3H in original gas is 0.0002 %, but after corona discharge that became 1.4960 % in sampled gas No. 1 and 1.0220 % in No. 2, respectively.

Table. 2 Condition of Sampled Gases

Sampled Gases		Condition of Corona Discharge				Purity (%)
		Polarity	Total Corona Current	Hours	Pressure	
No. 1	c-C_4F_8 only	Negative	200 μA	2 hr.	1.4 kg/cm² abs.	98.0104 (98.4549)*
No. 2	c-C_4F_8+N_2O 95 : 5 % Vol.	Negative	200 μA	2 hr.	1.2 kg/cm² abs.	98.3452 (98.7802)*
No. 3	Pure c-C_4F_8	not exposed to Corona Discharge				99.5246 (99.9716)*

* means the purity of the gases taken off H_2O.

(2) KC-216 which was the poisonous materials was not detected.

(3) Another fluorides were little detected. (In consideration of the sensitivity of gaschromatograph, the rest amounts are at least less than 0.0001 %.)

(4) CO_2 and H_2O hardly increased even after the corona discharge.

At present the authors carry on the investigations of the gaschromatographic analysis in more detail.

8. Conclusions

(1) It is pointed out that the κ-I_t characteristics of C_2F_6 cannot be always represented by the equation of $\kappa I_t^B=A$, like in the case of c-C_4F_8.

(2) The κ-I_t characteristics of $N_2O\oplus$ are similar to those of $N_2\oplus$. On the contrary, in the characteristics of the negative corona, there are remarkable differences between $N_2O\ominus$ and $N_2\ominus$.

(3) The corona starting voltage V_s of C_2F_6 mixing with N_2O increases a little when the volume percentage of N_2O is about 2 %. And in the characteristic curve of V_s in $SF_6 \ominus$ mixing with N_2O, a maximum point arises at N_2O $v.\% = 5\sim10\%$.

(4) It is worth considering to mix N_2O with perfluorocarbon in application to electrical insulation. Because N_2O is effective to prevent carbon accumulation on the electrodes.

(5) Even if N_2O is mixed with perfluorocarbon below ca. 5 %, the changes of the corona current distribution are not always large.

(6) The results of the gaschromatographic analysis gives that c-C_4F_8 is decomposed by the corona discharge. CF_3H is the most of all the decomposed products.

Acknowledgements

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