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Characteristics of Corona Discharge in SF_6-N_2 Gas Mixture

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***Abstract*— The sulfur hexafluoride (SF_6) has been categorized as a greenhouse gas, therefore the search for a replacement gas becomes top priorities to electrical engineers. The purpose of this experimental work is to investigate the behavior of SF_6-N_2 mixtures with low amount of SF_6 (10%) that can be realistically considered as a potential substitute of pure SF_6. The mobility of the charge carriers determined for high pressures and with highly non-uniform fields is inversely proportional to the gas density (N) and decreases with the increase of the percentage of SF_6 in the mixture. For the same conditions the onset corona discharge voltages have been determined. The results show that for low concentrations of SF_6 the increase of the onset voltage is relatively substantial, which can be an advantage for the substitution of SF_6.**

***Index Terms*—**Corona discharge, Ionic mobility, SF_6-N_2 mixture, sulphur hexafluoride.

I. INTRODUCTION

As the size of high voltage equipments increases the cost of SF_6 as an insulating gas becomes appreciably high. Moreover, its ability to absorb and reemit IR makes it a potent greenhouse gas [1-2]. With its high lifetime (more than 2000 years), it accumulates in the atmosphere and contribute to the global warming. Therefore, SF_6 will be severely controlled in the next years and the research of a substitute with little environmental impact is of growing interest.

SF_6-N_2 mixtures with 10% of SF_6 are likely to be a good solution mainly due to the synergetic effect of the nitrogen. Conduction phenomena in SF_6 and nitrogen (N_2) have been studied extensively by several authors [3-7]. For SF_6 the mobility was measured essentially with drift tube method. In our knowledge there is no measurements with indirect method using current-voltage characteristics in pure SF_6 and SF_6-N_2 mixtures.

In the present work a tip-plane configuration was used . The results were obtained for high pressures (2 to 14 bars) and for different tip radii. For the same conditions the onset corona discharge voltages have been determined. Most of the data available deals with the breakdown voltages rather than the threshold voltage of corona discharge.

II. EXPERIMENTAL PROCEDURE

Experiments were made in a stainless-steel cell of 50 cc is equipped with two quartz windows necessary for light detection as shown in fig.1. Electrodes in a tip-to-plane configuration were mounted inside the cell. The tip electrode of few micrometers is made of tungsten and prepared by electrolysis technique, steel tips are also used. The gap between the electrodes is nearly 10 mm. The tip electrode is connected to the high D.C. voltage. The stainless steel plane electrode with a radius of 12 mm is connected to an electrometer which measures currents down to some microamperes. Before the cell was filled with the gas, pumping was undertaken pushing the vacuum down to nearly 5.10^{-2} Pa. The gas was introduced in the cell without prior purification. The SF_6 used with a purity of 99.97%. The current was measured when the voltage varies upwards and downwards, and after each set of measurements a resting time is observed to allow the mixture to settle down. The tips are regularly changed in order to limit radius variations due to the deposit of sulfur and erosion. Analysis of used tips by electronic microscopy shows that the tip electrode was covered by a layer of sulfur.

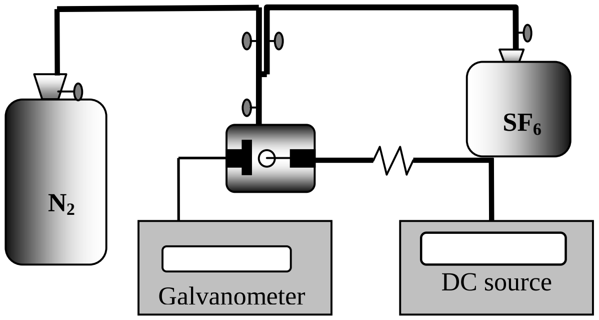

Fig. 1. Experimental set-up.

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III. RESULTS AND DISCUSSION

In tip-plane geometry the drift region is located outside the ionization region, where the ions and electrons drift in an electric field too low for creation of a new charge. Using the asymmetrical geometry and the appropriate boundary conditions, the value of the saturated current (I_s), can be obtained.

R. Sigmond [8] consider the Warburg distribution [9] on the plane electrode and for a constant mobility, he obtained, the unipolar saturation formula:

$$I_s = 2\frac{\mu\varepsilon}{d}V^2 \tag{1}$$

Where μ is the mobility, ε_0 is the permittivity, d is the gap length and V is the voltage.
Ionic mobility is deduced from the slopes the curves of $\sqrt{I}$ (V) drawn in fig. 2, for a gas mixture of 10%SF_6-90%N_2 with different pressures

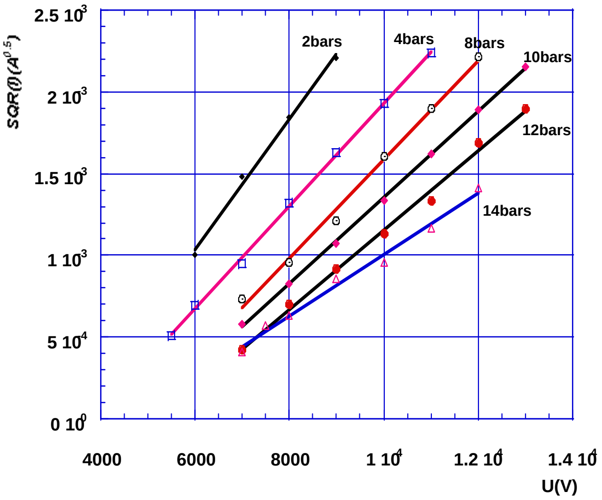

Fig. 2. Variation of $\sqrt{I}$ with voltage for different pressures in 10%SF_6-90%N_2 mixture.

In fig.3, the mobilities of SF_6 -N_2 gas mixture with different amounts of SF_6 admixtures are shown. They increase with the decrease of the percentage of SF_6 in the gas mixture. The Langevin [10] prediction of the mobility does agree with those measured for pure SF_6.
The mobilities for SF_6-N_2 gas mixtures with 10% of SF_6 for negative and positive polarity are shown in fig.4. The results show that for 10% of SF_6 in the gas mixture the mobility obeys the 1/N law as found by [11]. The gap between the negative and positive polarity is not significant. Therefore, the polarity effect is negligible.

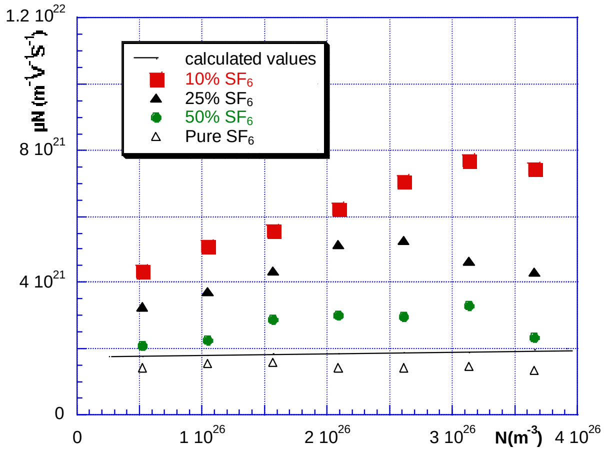

Fig. 3. The curves μN versus the density (N) of negative ions with different amounts of SF_6 in the SF_6-N_2 gas mixture.

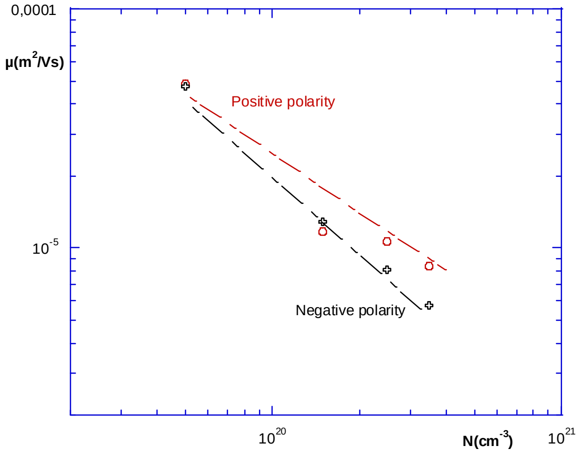

Fig. 4. Deduced mobility for SF_6-N_2 gas mixtures with 10% of SF_6 using negative and positive polarities.

In fig.5, the effect of tip radius is shown. The mobility increases with the increase of the tip radius.

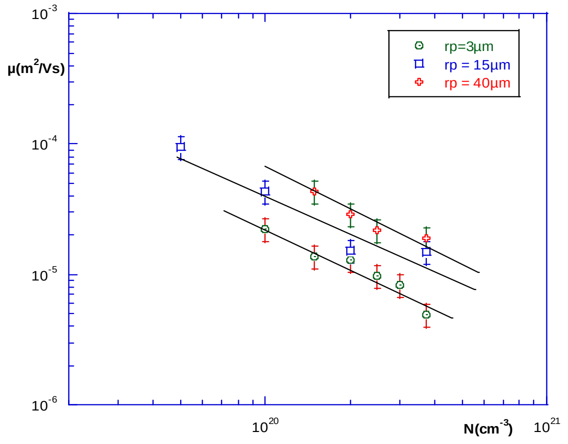

Fig. 5. Deduced mobility for SF_6-N_2 gas mixtures with 10% of SF_6 for different tip radius (r_p) for negative polarities.

In fig. 6, corona discharge onset voltages have been presented for negative and positive polarities with 10% of SF_6 in the gas mixtures. As it can be seen the effect of polarity is very noticeable and the onset voltages for positive polarity are clearly higher than those of the negative polarity.

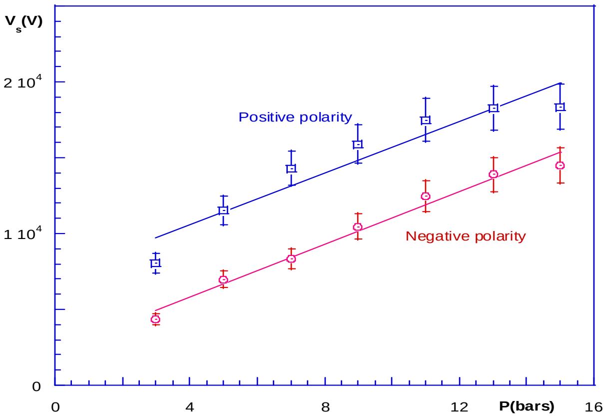

Fig. 6. Corona discharge onset voltages for negative and positive polarities with 10% of SF_6 in the gas mixtures.

The onset voltages for SF_6-N_2 gas mixtures with 10% of SF_6 for different tip radius (r_p) for negative polarity are sketched in fig.7. The values of inception voltages increase with the rise of the gas pressure. Higher values are obtained with higher tip radii.

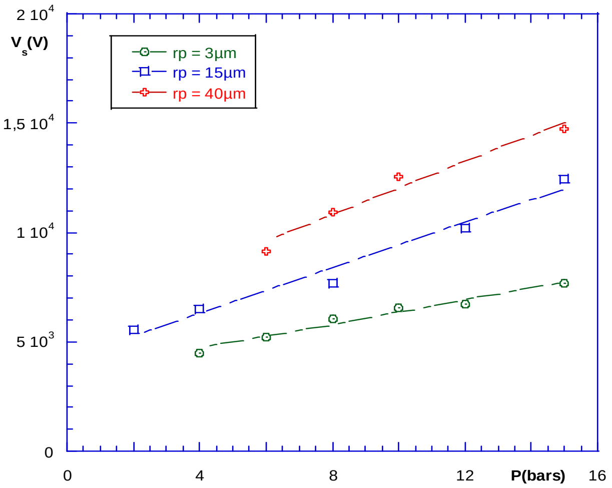

Fig. 7. Onset voltages for SF_6-N_2 gas mixtures with 10% of SF_6 for different tip radius (r_p) for negative polarity.

In fig.8, are plotted the curves of corona discharge onset voltage versus the amount of SF_6 in the mixture at 5 and 10 bars. The fast rise of the onset voltage in the region of low content of SF_6 (0 to 20% SF_6) is observed for both polarities. It can also be seen that the voltages are higher for elevated values of the pressure. Beyond 20% of SF_6, the increase of the onset voltage is less pronounced and it tends towards saturation.

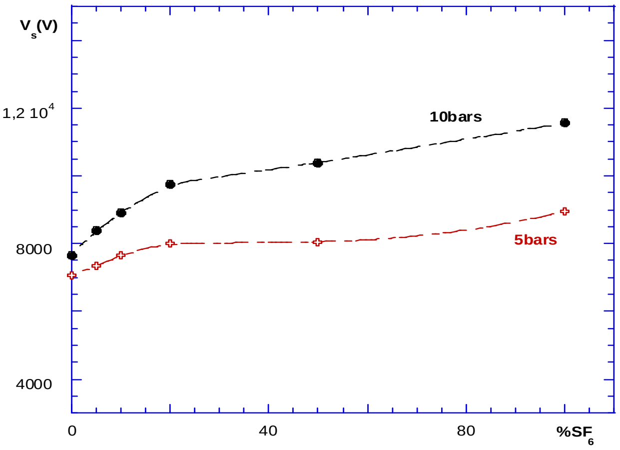

Fig. 8. Corona discharge onset voltage vs % content of SF_6 in the mixture (negative polarity).

From the curves on fig. 6 and 7, we can see that experimental values of corona inception voltages (Vs) increase linearly with pressure. In fig. 8, the values tend to saturate. Such deviations are often attributed to surface effects, which are more sensitive at high pressure [12]. Another reason is the change in surface conditions during experiments. Surface analysis using electronic microscopy shows that there's some deposit on the tip after a set of electric discharge, this deposit is composed of fluorine and sulphur, and such effect can explain the saturation phenomenon for higher pressures. At last, the saturation could be attributed to concentration of space charge which could be stopped by electrical interaction. At low concentrations of SF_6 below 20%, the rise of V_s is substantial before it slows down for higher concentrations. This tendency is also true for positive polarity but with higher values of V_s.

IV. CONCLUSION

Charge carriers mobility increases with the reduction of SF_6 content in the gas and it is inversely proportional to the gas density. The effect of polarity is not significant on the mobility. The tip radii do affect both the values of the mobility and the onset voltage of the corona discharge. The latter increases rapidly in the region of low SF_6 content, which is a good argument for potential substitution of SF_6 by SF_6-N_2 mixtures with low amount of SF_6, especially in highly divergent fields.

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