IMPULSE BREAKDOWN CHARACTERISTICS AND COST/BENEFIT ANALYSIS OF $SF_6/CCl_2F_2/CO_2$ MIXTURES

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ABSTRACT

A comprehensive study has been carried out in $SF_6/CCl_2F_2/CO_2$ mixtures to measure 50% breakdown voltages (V_{50}) using both positive and negative polarity lightning impulse (1.2/50 μs) voltages under non-uniform fields (5 mm. rod - 230 mm plane electrode) over a pressure range of 0.1 to 0.5 MPa for a gap spacing of 20 mm. The sum of SF_6 and CCl_2F_2 concentrations in the mixture was always maintained in the range of 21 to 40%, rest being CO_2.

Among the different sets of $SF_6/CCl_2F_2/CO_2$ mixtures studied, two ternary mixtures, namely 20% SF_6/20% CCl_2F_2/60% CO_2 and 30% SF_6/10% CCl_2F_2/60% CO_2 are found superior to SF_6.

From the known gas content in the mixtures and from the measured breakdown voltages a cost/benefit analysis has been carried out for the various mixtures investigated. A striking feature of this analysis is that the most promising ternary gas mixture, namely, 30% SF_6/10% CCl_2F_2/60% CO_2 costs only 33% of the cost of pure SF_6, giving 110% to 170% positive breakdown strength, and 90 to 100% negative breakdown strength as compared to that of pure SF_6.

INTRODUCTION

It is well known that in the application of gaseous insulation in GIS, the investigations of inhomogeneous field breakdown in electronegative gases/gas mixtures containing SF_6 are of considerable practical significance [1].

It appears from the earlier investigations [2] that the gas mixtures containing SF_6 and CO_2 in combination with CCl_2F_2 can be expected to have a breakdown strength equal to that of 100% SF_6, with a potential cost saving of upto 67% for the best mixtures. Also mixtures having CO_2 in SF_6/chlorofluoromethane mixtures were found to be very effective in suppressing carbon formation after breakdown.

EXPERIMENTAL APPARATUS AND PROCEDURE

The experiments were performed using a Marx-type, 10 stage impulse voltage generator of 500 kV rating. A cylindrical mild steel pressure chamber having a volume of 0.12 m^3, and fitted with a high voltage bushing was used. The electrode arrangement consists of a 5 mm dia stainless steel rod of hemispherical termination and a 230 mm dia brass plane of Rogowski profile. The gap distance between the electrodes was 20 mm, measured to an accuracy of better than $\pm$ 0.1%. $SF_6/CCl_2F_2/CO_2$ gas mixture, pressures used were in the

range of 0.1 to 0.5 MPa (1 to 5 bar). The concentration of SF_6, CCl_2F_2 and CO_2 content in the mixture was as follows:
a) SF_6 (1 to 20%), CCl_2F_2 (20% fixed) and the rest CO_2 (79% to 60%) and,
b) SF_6 (1 to 30%), CCl_2F_2 (39 to 10%) and CO_2 (60% fixed).

The gases (SF_6, CCl_2F_2 and CO_2) of cylinder grade purity (99.5%) were used in this study. Gas mixtures were prepared using the method of partial pressures to an accuracy of ± 0.2%. The 50% breakdown voltages (V_{50}) have been measured using statistical methods, namely, the step-by-step method and the Bakken's method [3]. The values obtained by both the methods were in very good agreement (± 3%). These variations however do not indicate any uncertainty in V_{50}, and during this study, the V_{50} could always be reproduced to within ± 2%. In evaluating cost analysis, the cost per volume of SF_6 (1.0) for CO_2 and CCl_2F_2 have been calculated as 0.007 and 0.21 respectively.

RESULTS AND DISCUSSION

a) Breakdown in $SF_6/CCl_2F_2/CO_2$ Mixtures

Figures 1 and 2 show a comparison between the impulse breakdown voltage - pressure characteristics for the 20 mm rod-plane gap in pure CO_2, for 20% CCl_2F_2/80% CO_2 mixtures, for pure SF_6 and for two sets of $SF_6/CCl_2F_2/CO_2$ mixtures.

Figure 1 illustrates, the data of $SF_6/CCl_2F_2/CO_2$ mixtures (1/20/79, 5/20,75, 10/20/70 and 20/20/60) wherein the positive breakdown voltages of 20% SF_6/20% CCl_2F_2/60% CO_2 mixture only is higher than those of pure CO_2, pure SF_6 and 20% CCl_2F_2/80% CO_2 mixture over the complete pressure range studied. On the otherhand, the negative breakdown voltage of pure SF_6 is higher than that of all the mixtures studied. A similar trend in voltage-pressure characteristics can also be seen from Figure 2, which shows the data of $SF_6/CCl_2F_2/CO_2$ mixtures (1/39/60, 5/35/60, 10/30/60, 20/20/60 and 30/10/60) with different compositions investigated. It is interesting to note that at higher pressures (> 0.4 MPa), the positive breakdown voltages of pure SF_6 are much lower than those of the binary mixtures (20% CCl_2F_2/80% CO_2) and all the ternary mixtures ($SF_6/CCl_2F_2/CO_2$) studied. It can be seen that the dielectric strength of two ternary mixtures 20% SF_6/20% CCl_2F_2/60% CO_2 and 30% SF_6/10% CCl_2F_2/60% CO_2 are found superior to that of pure SF_6, especially under positive polarity in the pressure range of 0.1 to 0.5 MPa.

b) Cost/Benefit Analysis of $SF_6/CCl_2F_2/CO_2$ Mixtures

In order to minimize the total cost of the gas in Compressed Gas Insulated Systems (GIS), CCl_2F_2 is also being tried as a third component gas with SF_6, CO_2, in binary/ternary mixtures as a promising candidate for practical use.

In view of the above consideration, a cost/benefit analysis was carried out from the various mixtures investigated in the present study. Figures 3 and 4 present the positive and negative relative dielectric strengths, V_{50}^R (V_{50} of mixture/V_{50} of pure SF_6) with cost ratio C_R for different ternary mixtures studied at a gap of 20 mm. In these figures the results are shown in the form of histograms in which, for a given mixture the data are shown separately at the five pressures investigated.

It can be clearly seen from the Fig. 3(a to h) which show the positive relative dielectric strength ratios to lie between 0.73 to 0.1 in the pressure range 0.1 to 0.3 MPa, while at higher pressures (> 0.4 MPa), these ratios reach maximum levels even higher than that for SF_6 (1.0) to lie in the range 1.0 to 1.7. The negative relative breakdown strength V_{50}^R of all the ternary mixture lie between 0.72 to 1.0 over all the pressure range investigated (Fig. 4). The cost ratios of all the eight sets of mixtures vary between 0.06 to 0.33 relative to pure SF_6 (1.0).

The increase in positive dielectric strength caused by adding CO_2 to SF_6 and CCl_2F_2 can be attributed to the effective slowing down of electrons via its strong low lying negative ion states [6]. Also, CCl_2F_2 in combination with SF_6 and CO_2 in all the $SF_6/CCl_2F_2/CO_2$ mixtures was found very effective in suppressing formation of free carbon, which was examined by inspecting the pressure chamber, electrodes, etc., after breakdown.

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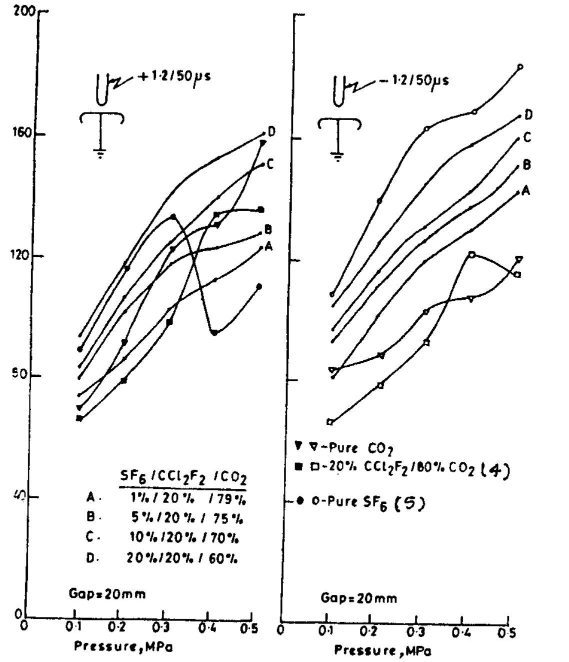

Fig. 1 Impulse breakdown voltage V_{50} against pressure for positive and negative rod-plane gaps in $SF_6/CCl_2F_2/CO_2$ mixtures.

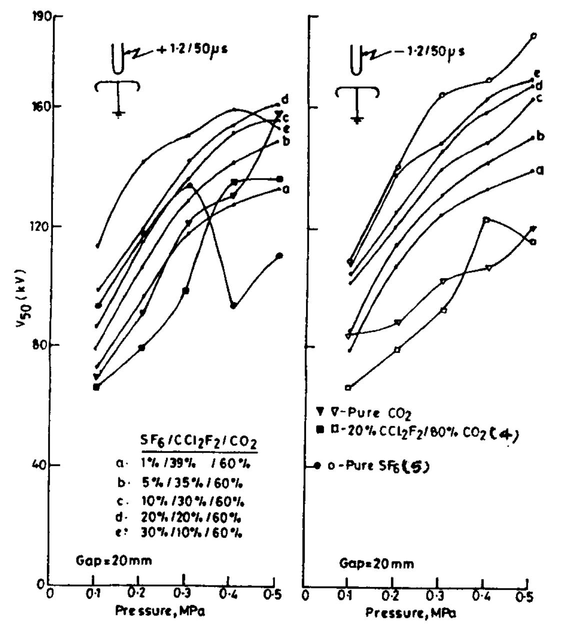

Fig. 2 Impulse breakdown voltage V_{50} against pressure for positive and negative rod-plane gaps in $SF_6/CCl_2F_2/CO_2$ mixtures.

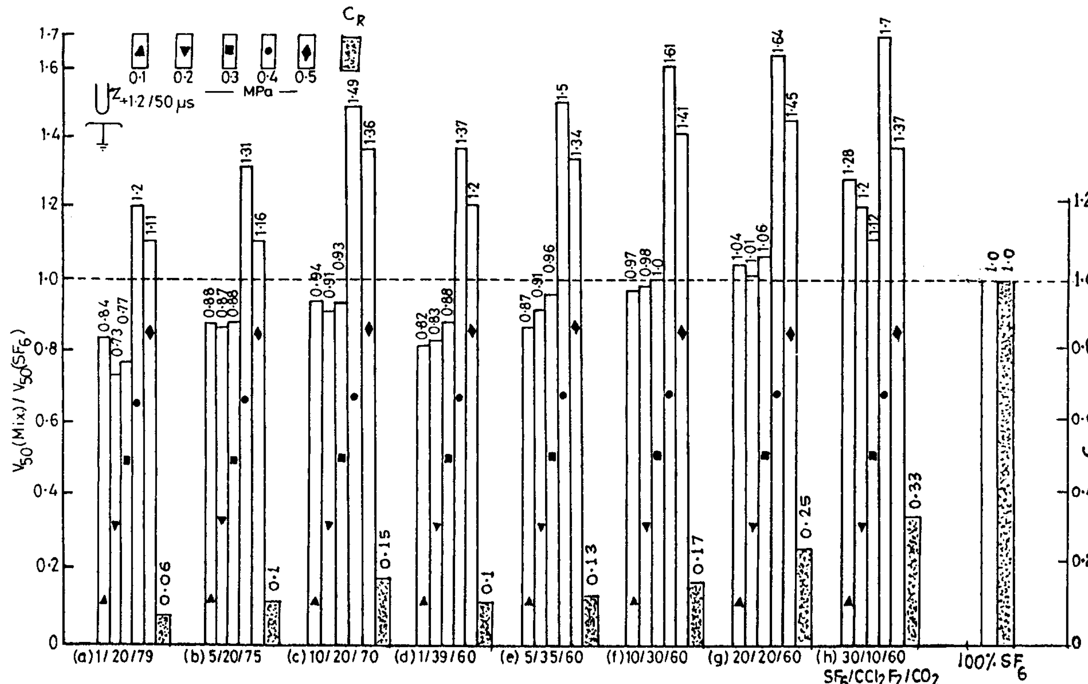

Fig. 3 Histograms of relative impulse breakdown strength $V_{50}(Mix)/V_{50}(SF_6)$ of positive rod-plane gaps with cost Ratio C_R for different ternary gas mixtures ($SF_6/CCl_2F_2/CO_2$) for different pressures, p at a gap of 20mm.

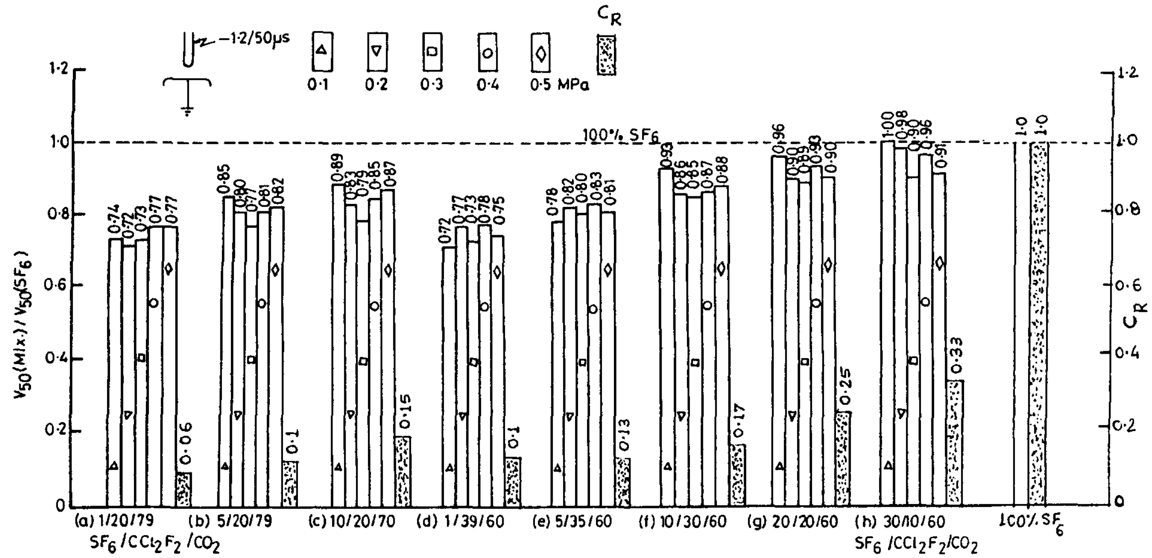

Fig. 4 Histograms of relative impulse breakdown strength $V_{50}(Mix)/V_{50}(SF_6)$ negative rod–plane gaps with cost Ratio C_R for different ternary gas mixtures ($SF_6/CCl_2F_2/CO_2$) for different pressures, p. at a gap of 20mm.