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EXPERIMENTAL STUDY OF PARTICLE-INITIATED BREAKDOWN IN NON-UNIFORM FIELDS

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ABSTRACT

Electrical insulation performance of compressed gas insulated systems and apparatus is adversely affected by metallic particle contaminants. This paper presents experimental results for the effect of the more realistic wire-shaped (filamentary) particles on the breakdown voltages of non-uniform field gaps. The effect of the particle size and material as well as gap spacing on the breakdown voltage has been presented and discussed in this work. In non-uniform field, the location of conducting particle can be considered as an important factor. Therefore, the determination of the critical location of the contaminated particle has been carried out. The effect of the particle size, gap spacing and the nonuniformity factor of the field on the critical distance has been presented.

KEYWORDS :

Gas insulated systems - Non-uniform field gaps - Critical location - Particle initiated breakdown

INTRODUCTION

There is a growing interest in the application of high pressure gases for electrical insulation in high voltage apparatus and equipment. The development of these systems, traditionally known as gas insulated substations (GIS) and transmission lines (GITL), has made rapid progress over the past two decades [1-3]. Fast development in those systems is still being witnessed. The dielectric strength of compressed gas insulation in GIS is adversely affected by different phenomena which appear during its operation such as, electrode surface roughness, humidity and particle contamination. The sensitivity of high pressure gases to dust and conducting particles is a serious limitation for practical GIS application. The insulation strength of gas insulated substations can be greatly reduced by the presence of contamination in the form of conducting particles [4-12]. Generally, the conducting particles encountered in practical GIS systems are filamentary in shape. A detailed study of the effects of metallic particles on breakdown is therefore important both for elucidation of the mechanism of breakdown and for the application of compressed gas insulation in practical high voltage systems. The withstand voltage of contaminated GIS depends on the particle shape, size, material, location, the gas pressure and the nature of the applied field.

The present work provides an experimental study to the effect of particle contaminant in non-uniform fields, i.e. hemisphere-to plate and rod-to-plate gaps, on the breakdown voltage of the gap. Aluminum and copper wire particles of different lengths and diameters are used. In non-uniform field, the location of conducting particle can be considered as an important factor. Therefore, the determination of the critical location, i.e the distance at which the particle has no effect on the withstand voltage of the gap, of the contaminated particle has been carried out. The effect of the particle diameter and length on the critical distances has been presented. Also, the effect of the nonuniformity factor of the field on the critical distance is investigated.

TEST EQUIPMENT AND PROCEDURE

The tests were performed on a hemisphere-to-plate and a rod-to-plate gaps. The electrodes which have been used are manufactured from brass with the following diameters, 38.0 mm for the hemisphere electrode, 27 mm for a rod electrode with an end cap and 100 mm for the earthing plate which having a Bruce profile. A concentric circles are drawn onto the earthing plate, their centers at the critical field line and having radii of 5.0, 10.0, 15.0 mm... .etc, to determine the critical distance beyond which the breakdown voltage dose not affected by the presence of the contaminated particle.

An aluminum wire particles were introduced into the electrode system at the critical field line before the voltage was applied. The filamentary particles were 10.0, 7.0, 5.0, and 3.0 mm in length and 1.5, 1.0 and 0.5 mm in diameter, with square-cut ends. A copper wire particle of length 10.0 mm and 1.5 mm diameter has been used for comparison.

The high voltage DC was obtained from a 60 kV, 1 mA DC power supply. The voltage of the HV electrode was gradually increased at a constant rate of about 4 kV/sec until the gap breaks down. The average of at least 12 breakdowns was taken to estimate the breakdown voltage. The experimental results were corrected to the normal pressure and temperature which are commonly used.

RESULTS AND DISCUSSIONS

The particle initially situated on the lower electrode at the critical field line. The applied voltage was raised steadily till the gap breaks down. A different particle size and material as well as gap spacing were used.

Hemisphere-To-Plate Gap

The variation of the breakdown voltage with the particle diameter at a gap spacing of 15.0 mm is shown in Fig.1. It can be seen that as the particle diameter increases the breakdown voltage increases. For example, the breakdown voltage increases from about 15.0 kV to 21.0 kV as the particle diameter increases from 0.5 to 1.5 mm respectively. This means that the thiner particle reduces the breakdown voltage more drastically. Also, it must be mentioned that the breakdown voltage of the clean gap is about 38.0 kV. So, the presence of conducting particles lower the breakdown voltage of the gap to about half the value of the clean gap. It appears also that the length of conducting particle has a negligible effect on the withstand voltage of the gap.

Fig. (2) shows the breakdown voltage versus the gap spacing for different particle diameters. It can be seen from the figure that the breakdown voltage of a fixed gap decreases as the diameter of the wire particle decreases. Also, it is observed that as the gap spacing decreases the hazard of the contaminating particles increases. For example, the breakdown voltage of a 20 mm gap with a contaminated particle having 0.5 mm diameter is lowered to about 40% of that of the clean gap, while it decreases with the same particle to about 29% of that of the clean gap for gap spacing of 10.0 mm. This may be explained due to the fact that the nonuniformity of the field increases as the gap spacing increases. Thus the electric field become small at the ground electrode. Therefore the particle needs a higher voltage to lift off. This is the reason for the observed lower percentage reduction in the breakdown voltage as the gap spacing becomes higher.

The breakdown voltage as a function of gap spacing using different particle materials is shown in Fig. (3). The particle length and diameter are chosen to be 10 mm and 1.5 mm, respectively. It is shown that the breakdown voltage of a gap with a copper particles is greater than that with aluminum particles. It is found that the breakdown voltage of a gap spacing of 10.0 mm varies from about 47% of that of the clean gap with an aluminum particle to about 70% of that of the clean gap with copper particles having the same size. This may be explained due to the higher density of copper particles as it needs more lifting force to cross the gap.

Rod-To-Plate Gap

To study the effect of nonuniformity factor on the breakdown in the presence of contaminated particles, rod-to-plate electrodes have been used.

Figs. (4) and (5) show the breakdown voltage as a function of the aluminum particle diameter for different particle length at gap spacings of 15.0 and 25.0 mm, respectively. It can be seen from the figures that the breakdown voltage of the gap decreases with decreasing both the particle diameter and the particle length. It is found that at gap spacing of 25.0 mm the breakdown voltage increases from about 74% to about 89% of that of the clean gap as the particle length increases from 3.0 to 10.0 mm with a diameter of 1.5 mm, while it increases from about 61% to about 65% of that of the clean gap as the particle length increases from 3.0 mm to 10.0 mm but with a diameter of 0.5 mm. It can be concluded that the effect of the particle length decreases with decreasing its diameter.It is found that the presence of the contaminating particles lower the breakdown voltage of the gap markedly. It appears that as the gap spacing increases the effect of the particle decreases. Wherever, at gap spacing of 25.0 mm with an aluminum particle has a 3 mm length and 0.5 mm diameter the breakdown voltage will lowered to about 61% of that of the clean gap, while for the same particle but with a gap spacing of 15.0 mm the breakdown voltage will lowered to about 39% of that of the clean gap.

Critical Distances

The location of the contaminated particle in non-uniform field gaps is an important factor in the determination of the breakdown voltage of such gap. This section study the effect of the particle location on the gap breakdown voltages. A concentric circles are drawn on the earthing plate divided the plate with an equal distances of 5 mm. The center of the concentric circles is the intersection point of the critical field line with the earthing plate. The breakdown voltage of the gap at each distance is determined by putting the particle touching the circle and the applied voltage is raised at the constant rate until breakdown occurs.

The breakdown voltage of a hemisphere-to-plate gap as a function of the distance from the plate center with different aluminum particle diameters at a gap spacing of 15.0 mm is shown in Fig. 6. It is seen that the breakdown voltage decreases as the particle diameter decreases at all particle locations. Also, it is found that the breakdown voltage increases as the contaminating particle moves away from the center of the concentric circles. The intersections of these curves and the line represents the mean clean gap breakdown voltage determine the critical distances, X_c, of the contaminated particles at which the particle has no effect on the gap breakdown voltage. It is shown that the critical distance decreases with increasing the particle diameter. The effect of the aluminum particle length on the critical distance of a hemisphere-to-plate gap is shown in Fig. 7. It is observed that the particle length has a negligible effect.

Fig. 8 shows the breakdown voltage of a rod-to-plate gap versus the distance from the plate center with different aluminum particle diameters at a gap spacing of 15.0 mm. It is appears that the critical distance decreases with increasing the particle diameter. The effect of the aluminum particle length on the critical distance of a rod-to-plate gap is shown in Fig. 9. It is seen that the particle length has a small effect.

From the comparison of the two gap configurations, it is found that the critical distance decreases with increasing the nonuniformity factor of the field. The critical distance decreases from about 33.0 mm in a hemisphere-to-plate gap for a contaminating particle of 10.0 mm length and 0.5 mm diameter at 15.0 mm gap spacing to about 30.0 mm in a rod-to-plate gap for the same particle size and gap spacing. While it decreases from about 27.0 mm in a hemisphere-to-plate gap to about 20.0 mm in a rod-to-plate for the same gap spacing and particle length but with a particle diameter of 1.5 mm. This means that the critical distance decreases rapidly with the particle diameter. Also, this can lead to an important conclusion that in non-uniform field gaps the effect of the contaminating particle location decreases as the nonuniformity factor of the field increases.

CONCLUSIONS

1. The breakdown voltage of non-uniform field gaps is greatly affected by the presence of a contaminated particles.

2. For a hemisphere-to plate gap the particle diameter has a pronounced effect on the breakdown voltage, while the

particle length has a negligible effect.

3. For a rod-to-plate gap both particle diameter and length have an effect on the gap breakdown.

4. The particle location is found to be very important factor in determination of the breakdown voltage of the gap.

5. As the particle diameter increases the critical distance decreases and the gap can sustained a higher voltage, while the particle length has a small effect.

6. In non-uniform field gaps the effect of the contaminating particle location decreases as the nonuniformity factor of the field increases.

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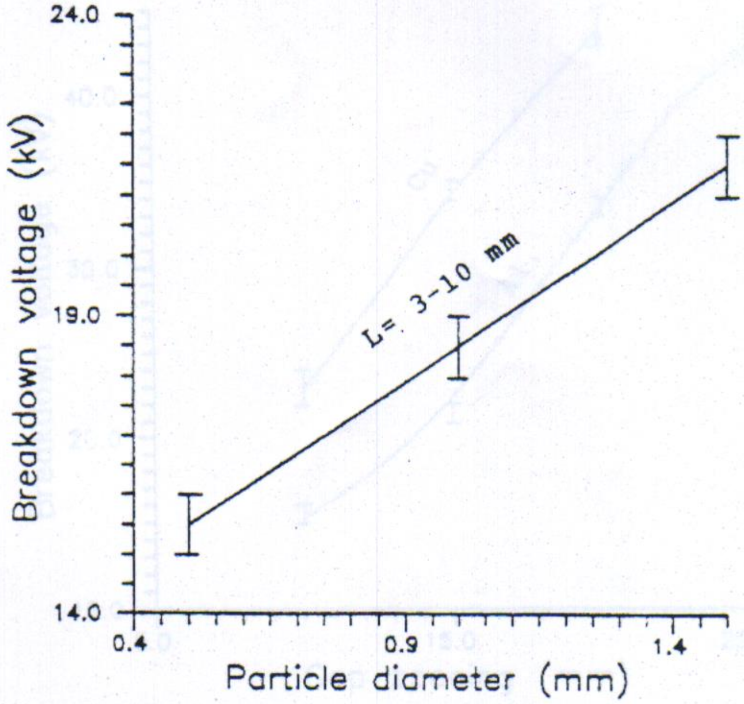

Fig. 1 Breakdown voltage as a function of aluminum particle diameter at gap spacing of 15 mm in a hemisphere-to-plate gap

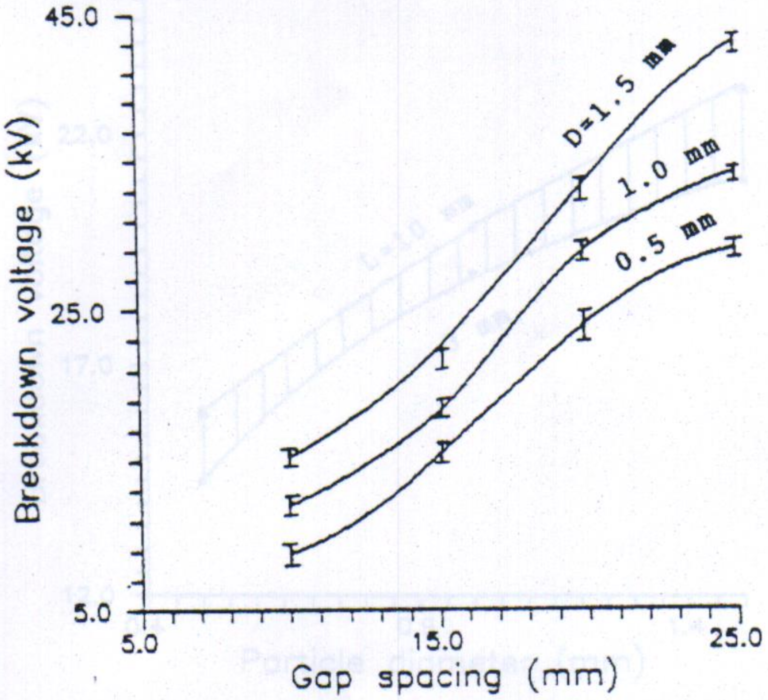

Fig. 2 Breakdown voltage versus gap spacing at different particle diameter in a hemisphere-to-plate gap

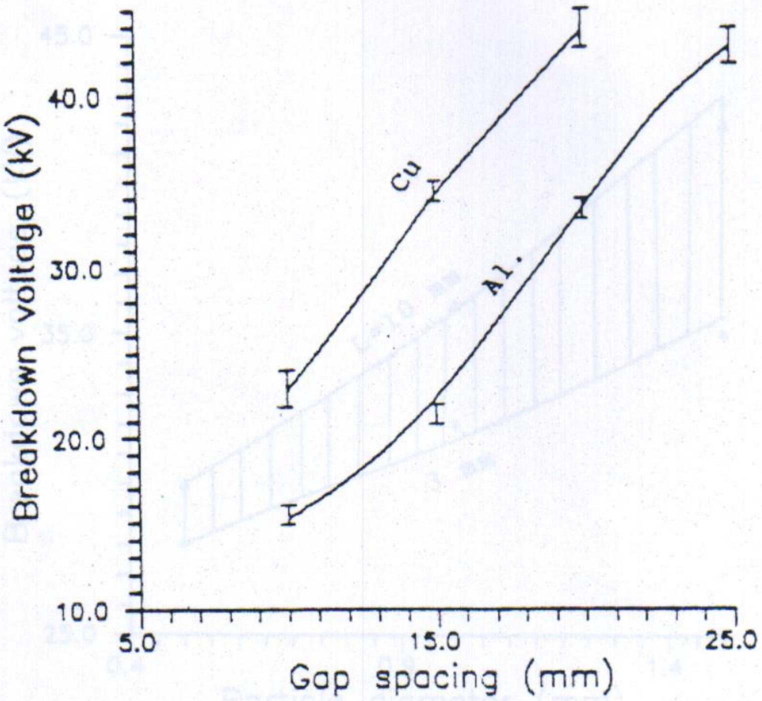

Fig. 3 Breakdown voltage versus gap spacing at different particle material in a hemisphere-to-plate gap

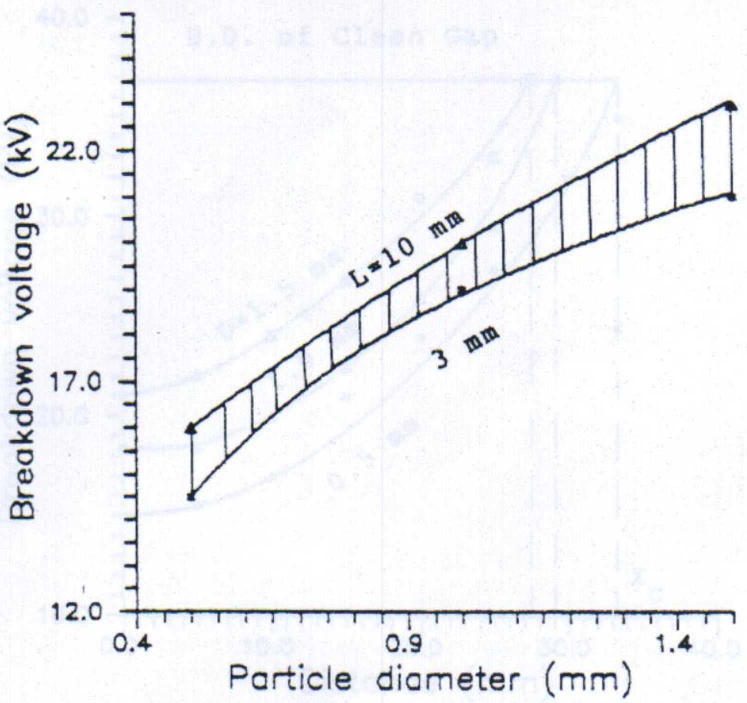

Fig. 4 Breakdown voltage of aluminum wire particle in a rod-to-plate gap of 15 mm spacing

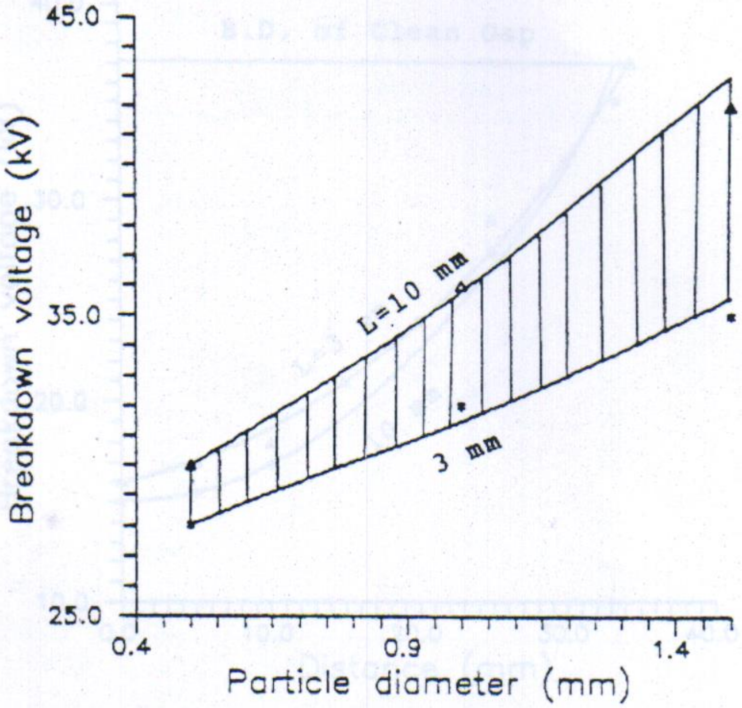

Fig. 5 Breakdown voltage of aluminum wire particle in a rod-to-plate gap of 25 mm spacing

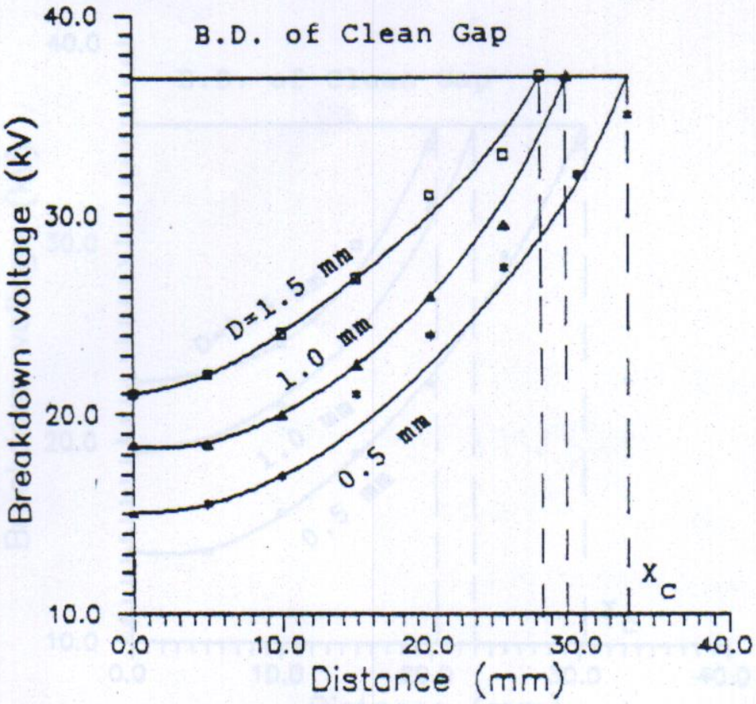

Fig 6 Critical distances, X_c, at different particle diameter in a hemisphere-to-plate gap of 15 mm spacing

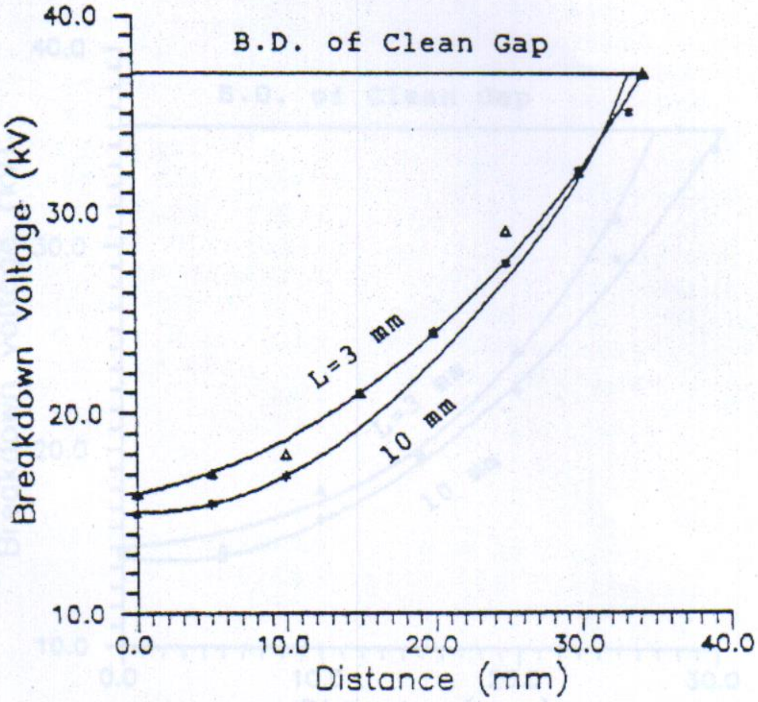

Fig 7 Critical distances at different particle length in a hemisphere-to-plate gap of 15 mm spacing

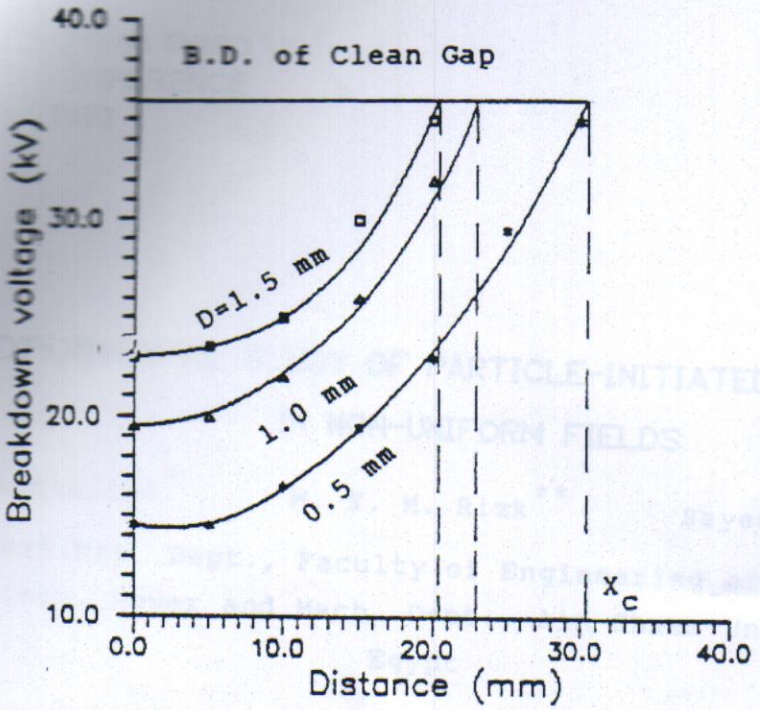

Fig 8 Critical distances at different particle diameter in a rod-to-plate gap of 15 mm spacing

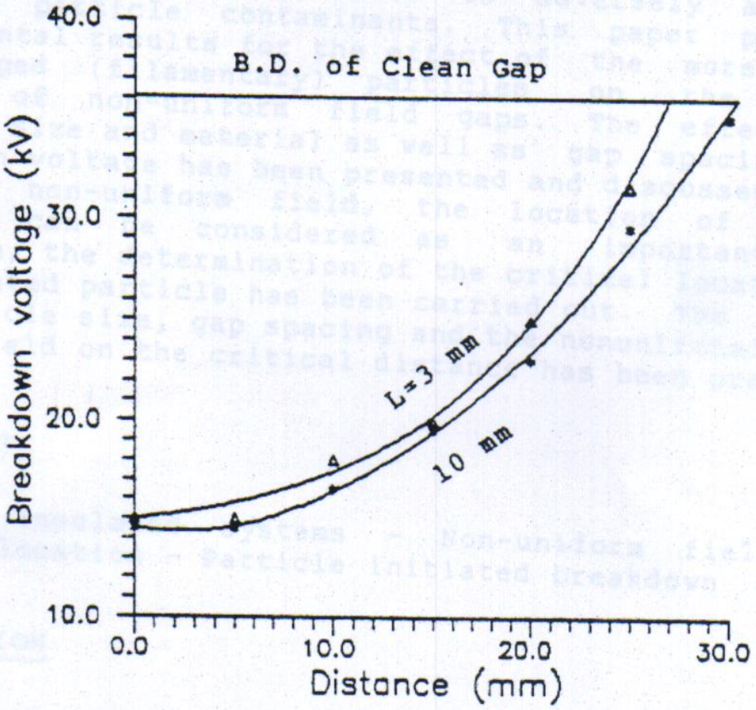

Fig 9 Critical distances at different particle length in a rod-to-plate gap of 15 mm spacing