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Influence of Polymer Insulating Barriers on the AC Breakdown Behaviour of Small Oil Gaps.

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INFLUENCE OF POLYMER INSULATING BARRIERS ON THE AC BREAKDOWN BEHAVIOUR OF SMALL OIL GAPS

تاثير حواجز البوليمر العازلة على سلوك جهود الانهيار المتغيرة لثغرات الزيت الصغيرة

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الخلاصة

يقدم البحث بنتائجة مساعدة فعالة فى تصميم عوازل البوليمر ـ الزيت المركبة اذ يقدم البحث تحليلا لنتائج معملية عن تاثير استخدام حواجز البوليمر العازلة على جهود الانهيار لثغرات الزيت الصغيرة.
تم اجراء التجارب باستخدام ثلاثة انواع من مواد البوليمر الشائعة الاستعمال كحواجز وهى مادة البولى فينيل كلورايد ومادة البوليستر ومادة البكالايت.
اظهرت النتائج بوضوح ان مواد البوليمر جميعهاتسبب زيادة كبيرة فى قوة العزل لثغرات الزيت سواء كان المجال الكهربى قليل التباعد او شديده.
امكن من التجارب استخلاص ان مواد البوليمر عالية المقاومه للقوس الكهربائى تتسبب فى زيادة قوة عزل الثغرة زيادة اكبر من مثيلاتها الاقل مقاومة للقوس الكهربائى مما يفسر زيادة قوة العزل للثغرة فى حالة حواجز البولى فينيل كلورايد عنها فى حالة حواجز البوليستر ويفسر ايضا انخفاض مستوى تحسين عزل الثغرة فى حالة البكاليت عنه فى حالتى البولى فينيل كلورايد والبوليستر.
يعطى البحث ايضا خطوطا ارشادية لانسب الاماكن لوضع الحواجز فى ثغرات الزيت يتفق مع التحليل النظرى لتاثير شحنات الفراغ المكتسبه بواسطة حواجز البوليمر على المجال الكهربى للثغرة. فى حالة ان يكون قطر حاجز البوليمر مساويا او اكبر من نصف بعد ثغرة الزيت يكون انسب مكان لوضع الحاجز فى منتصف الثغرة بينما اذا صغر قطر حاجز البوليمر عن ذلك يفضل ان يكون ملاصقا لاحد اقطاب الجهد العالى.

Abstract

The paper reports the influence of some different, currently used, polymer insulating barriers on the AC withstand voltage of small oil gaps. The experiments have been conducted using barrier samples of bakelite (Ba), polystyrene (PS) and polyvinyl chloride (PVC). The insulating barriers have been inserted in small oil gaps subjected to AC high voltage stress of weakly as well as, of very highly divergent fields. The improvement of the dielectric strength of oil gaps through the insertion of polymer barriers has been found to be dependent on the kind of barrier material, barrier placement in the gap, barrier dimensions as well as, on the degree of the field homogeniousity of the gap. Explanations of the different parameter effects are attempted by considering the different possible space charge distributions as well as, the special features of the used dielectric polymers. The achieved results are, not only important for barrier effect considerations, but also can be helpful as a guide for the design of oil - solid composite dielectrics.

1. INTRODUCTION

A stressed surface of a solid insulator, inserted in an oil insulation, is known to affect the AC - withstand voltage remarkably, compared to that of a pure oil gap. Generally, the electric field in the gap will be enhanced due to the following reasons. First, the surface roughness of the solid material [1]. Second, the modification of the electro - hydrodynamical movement in the oil caused by the solid, which in turn leads to vortexes and bubble generation at highly stressed locations in the insulation [2]. Third, the raised stored energy in the field caused by the presence of the solid dielectric [3].

This field enhancement explains the reduction in the breakdown voltage, which can be caused through the existance of tangentia to an oil insulation like that of spacers [1]. However, if the solid insulation is inserted perpendicular to the electric field lines in a field gap, the dielectric strength of the gap may be remarkably increased. In this case, the solid insulating material acts to control the space charge in the field gap [4]. This solid dielectric screening effect is known from the early work of Marx [5] and Roser [6]. It is called the barrier effect.

Due to the great importance of these dielectric screens in the high voltage engineering, a series of publications have been introduced reporting the barrier effects in air gaps [4,7,8]. The main feature of these investigations is studying the barrier effects on the breakdown voltage. Thereby, thin insulating paper barriers have been used as a model to find the space charge effect on the breakdown characteristics. In such a case, the space charge distribution is simple. Also, it is not impossible to measure the space charge distribution quantitatively [4].

Little attention has been paid to the effects of insulating barriers on the breakdown voltage of oil gaps. The few investigations regarding this subject have merely used paper and press-board insulating barriers [1,9,10].

Regarding the continuous increasing interest in using polymer insulating materials in high voltage equipments, it appears to be of great importance to investigate the breakdown features of composite polymer - oil dielectrics. Such investigations are of particular interest because of the special properties of the polymers, which are different of those of paper or press-board. Insulating polymers are of good electrical as well as, of good mechanical properties. Moreover, some of them show excellent charge storage capabilities and have received wide applications such as electrets [11].

The present work deals with the influence of some different, currently used, polymer insulating barrier materials on the AC withstand voltage of small oil gaps. To this extent, a simple experimental realization construction has been used. The effects of both very high and weak divergent electric field strengths, as those caused by conducting particles [12] and in usual operating conditions respectively, have been taken into account.

2. EXPERIMENTAL TECHNIQUES

A 60 - kV, semi - automatic testing rig with BSS / IES test vessel has been used to determine the dielectric strength of the transformer insulating oil. The used set has a motorised variable transformer to raise the voltage at a rate of 2 kV / second. When breakdown occurs, the voltage is held in the meter until it is reset [12].

Copper sphere gap electrodes of 1.3 cm diameter have been used to produce the weakly divergent electric field stress in an oil gap of 1 cm width. On the other hand, steel needles having tip radius of 30 Um and shaft length of 3 cm have been used to produce very high divergent electric field stress within the oil gap. The electrode surfaces of both sphere and needle gaps have been polished as smooth as possible before conducting the tests.

A polydimethylsiloxane silicone insulating oil having a conductivity of about 10 Exp-14 mho/ m and a relative permittivity of about 12.8 were used in the experiments. A great care has been taken to keep same oil quality during each test. The oil was kept at a moisture content below 10 ppm and a gas content below 2%. The small size of the testing vessel enabled the replacement of the oil after each test.

Rectangular and circular insulating polymer plates have been used as screening barriers. The samples used were of bakelite (Ba), polystyrene (PS) and polyvinyl chloride (PVC). All samples were 1 mm thick. The samples have been held by means of a very thin clasp of wood to an adjustment preparation, which permitted a fine graduated setting over a screw spindle using a hand wheel.

The plotted mean breakdown values in all reported results has been taken as the average of 50 independent breakdown realizations.

3. RESULTS AND DISCUSSION

Fig.1 illusrates the breakdown voltages versus the position of barrier for a sphere gap case of weakly divergent electric field stress caused by the sphere electrodes described before. The polymer barriers of Ba, PS and PVC were all of a rectangular shape having the dimensions 5 cm X 8 cm. With a 1-mm barrier thickness and a displacement of 1-mm in the 1 - cm gap width, experimental investigations of 10 different barrier positions could be realized. Thereby, for all next following figures, the position of barrier is defined as the distance "a" from the left surface of the barrier to the left electrode tip.

From Fig. 1 it can be seen that the polymer barriers strongly affects the breakdown voltage of the oil gap. In general, a remarkable increase in the dielectric strength of the oil gap has been achieved for all the three polymer barrier types and for all barrier positions. However, the influence of the polymer barriers varies from one material to another. Thus, it is evident from Fig.1 that the dielectric strength of the gap is slightly higher in the PVC barrier case than that in the PS barrier one. On the other hand, the dielectric strength of the gap in the case of Ba barriers is much lower than that of the PVC or PS barrier case.

The same remarks can be noticed in Fig.2, which illustrates the breakdown voltages versus the position of barrier for a needle - needle gap of very high divergent electric field caused by the needles described before. Also in this case, PVC barriers cause a higher enhancement to the dielectric strength of the oil gap than that caused by the PS or Ba barriers. Again, the barriers of Ba material are of much lower influence on the breakdown voltage of the oil gap than that caused by PVC or PS barriers.

The enhancement of the oil gap dielectric strength is about 35% in the sphere-gap case and about 56% for the needle - needle case, when PVC barriers are used. The barriers could raise the dielectric strength of the gap subjected to very high divergent electric fields to achieve the values caused by the barriers in the case of weakly divergent electric fields.

From figures 1 and 2 it can be generally seen that, the breakdown voltage of the gap slightly increases by increasing the distance between barrier and electrode. It reaches a maximum value when the barrier is at the gap center. This result is in accordance with that achieved in Ref. [8], for the influence of barriers on the breakdown voltage in air. However, it should be noted that the barrier dimensions used for achieving the results in Figs.1 and 2 are large compared with the oil gap width as well as, with the electrode dimensions. To have a precise idea about the barrier influence on the breakdown voltage, the barrier dimensions should be taken into consideration. To this extent, circular polymer barriers of different radii have been used to examine the effects of barrier area on the breakdown voltage of oil gaps for both cases of weakly divergent and very highly divergent electric fields.

Fig.3 and Fig.4 show the breakdown voltage versus barrier diameter for the sphere gap and the needle - needle gap respectively. In both cases PVC, PS and Ba barriers have been used. The barrier position was held fast at the center of the gap. It is obvious from figures 3 and 4 that the PVC barriers are the best suitable screens regarding the desired dielectric insulation strengthening of the gap, followed by the PS barriers and the Ba barriers, respectively. The breakdown voltage increases, in general, as the barrier diameter increases. The highst dielectric strength for the gap could be obtained for a barrier diameter in the order of half the gap length for all the investigated polymer materials. Higher dielectric strength could be achieved by the barriers in the case of the needle - needle gap than the sphere gap case. This can be attributed to the fact that, in both cases the electric field will be homogenized through the space charge stored by the barrier. Thus, in this case, the greater breakdown path in the needle - needle arrangement than that in the sphere gap case leads to higher breakdown voltages in the former one.

Figures 5 and 6 illustrate also the breakdown voltage versus barrier diameter for both cases, i.e. weakly divergent and highly divergent electric fields, but for barriers contacting one of the electrodes (a = 0). The main features found in Figs.3 and 4, for the case of barrier at the gap center, are also valid for this case. However, in the latter case, the achieved breakdown voltages in the needle - needle arrangement is lower compared with that in the sphere gap case (contrary to the results achieved when the barrier is placed at the center of the gap). This dissimilarity between the results in figures 5 and 6 and their corresponding cases in figures 3 and 4 can be attributed to the space-charge distribution. For the case that the barrier is at the gap center, space charge is considered to be distributed on the barrier area and it acts as a plate electrode, similar to the results described by Roser [6] for paper barriers in air. In this case the barrier causes a field homogenisity, which leads to higher breakdown voltages in the needle - needle electrode case as mentioned before. On the other hand, when the barrier is close to the electrode, it can be suggested that the charges are concentrated on the small area of the barrier which is in contact with the electrode. The field configuration is not largely changed in this case. The barrier acts only to lengthen the breakdown path. The influence of the field divergity remains nearly the same, which consequently leads to low breakdown voltages in the needle - needle arrangement compared with that of the sphere-gap case.

The better influence of PVC barriers evident in all test cases, can be attributed to the fact that PVC has the higher arc resistance in all the three investigated materials. Moreover, under the action of an electric arc, PVC abundantly envolves gaseous products of decomposition which foster the extinction of the arc. On the contrary, bakelite is of poor arc resistance and has a tendency to track . Thus, it can be concluded that, the higher the arc resistance of polymer materials is the better the materials for composite oil - solid dielectrics.

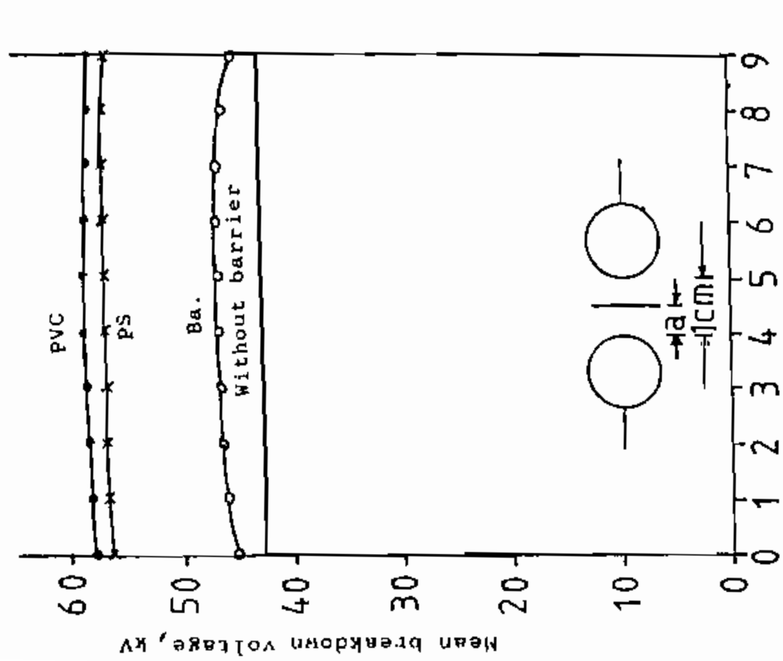

Fig 1 Breakdown voltages versus barrier position " a " for a sphere gap arrangement as described in text.

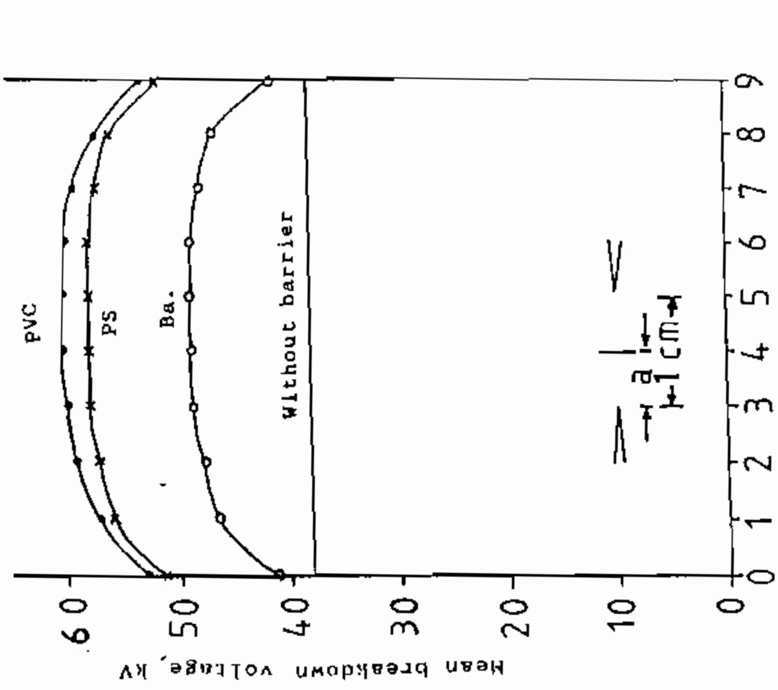

Fig.2. Breakdown voltages versus barrier position "a" for a needle - needle gap arrangement as described in text.

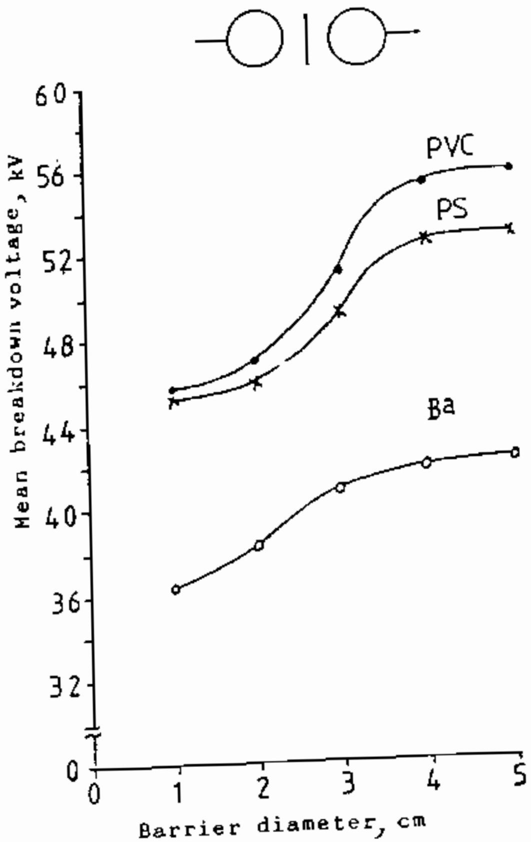

Fig.3. Breakdown voltages versus barrier diameter for the sphere gap arrangement. (Barrier at the gap center)

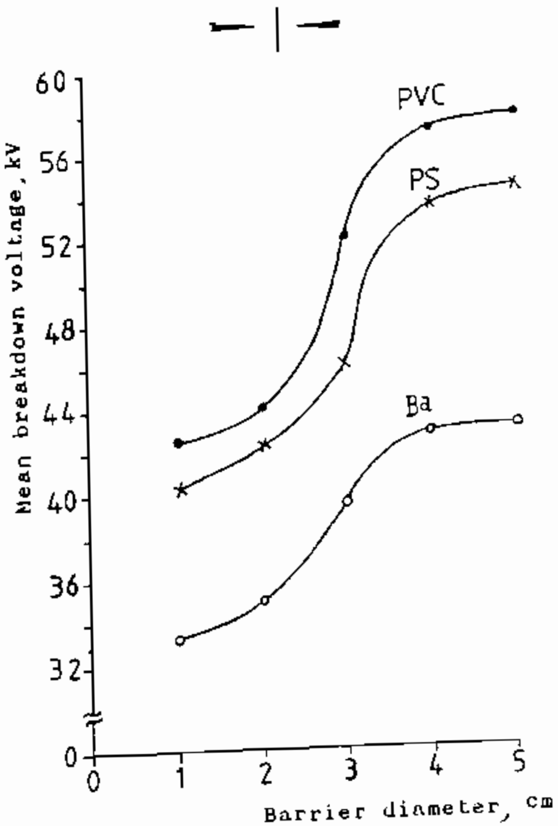

Fig.4. Breakdown voltages versus barrier diameter for the needle - needle arrangement. (Barrier at the gap center).

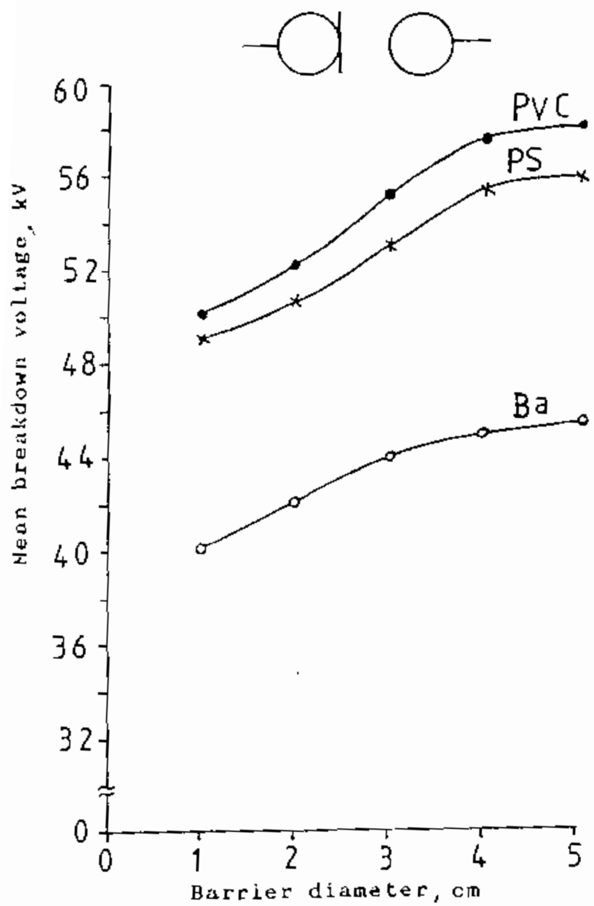

Fig.5. Breakdown voltages versus barrier diameter for the sphere gap arrangement. (Barrier contacts the electrode).

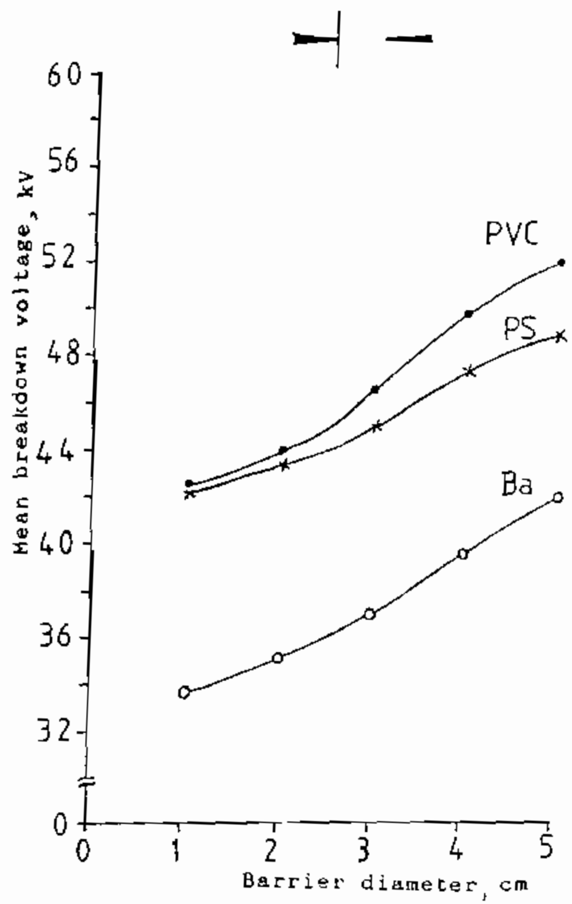

Fig.6. Breakdown voltages versus barrier diameter for the needle - needle arrangement. (Barrier contacts the electrode).

4. CONCLUSIONS

The influence of PVC, PS and bakelite polymer barriers on the breakdown behaviour of small oil gaps has been investigated and discussed in this paper.

A noticable improvement of the dielectric strength of oil gaps subjected to weakly divergent and very highly divergent electric fields may be observed for all the mentioned polymer barrier materials. However, PVC barriers have been found to be of much better influence than PS and bakelite barriers, regarding the enhancement of oil gap dielectric strength. This leads to the conclusion that, the higher the arc resistance of polymer materials is the more suitable the materials to be used for oil-solid dielectrics.

Polymer barriers placed at the center of oil gaps are thought to homogenize the electric field strength through their stored space charge, distributed on the barrier area. By this means, the dielectric strength of gaps subjected to very high divergent electric fields could be raised to such values as those resulting by the same polymer barriers for weakly divergent electric field case. Guide lines for the placement of polymer barriers have been deduced from the experimental results as follows. Barriers of diameters of nearly equal or greater than half the oil gap width are to be placed at the gap center. On the other hand, small barriers are more effective, if they contact the electrodes.

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