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Insulating barriers efficiency on the dielectric strength of organic ester oil gaps

***Abstract**. The article deals with the influence of the position and shape of insulating barrier on the dielectric strength of cone-plane electrode arrangement immersed in natural ester oil. It is shown that the effectiveness of the barrier is the highest when the barrier is located at the tip of cone electrode whatever the electrode gaps and/or the shape of barrier.*

***Streszczenie.** Artykuł dotyczy wpływu położenia i kształtu bariery izolacyjnej na wytrzymałość dielektryczną układu elektrod stożkowo-płaskich zanurzonych w naturalnym oleju estrowym. Pokazano, że skuteczność bariery jest najwyższa, gdy bariera znajduje się na wierzchołku elektrody stożkowej niezależnie od odstępu elektrod i / lub kształtu bariery (**Efektywności bariery dielektrycznej dla wytrzymałości przerw olejowych z estrem organicznym)**.*

Keywords: natural ester, mineral oil, barrier efficiency.
Słowa kluczowe: ester naturalny, olej mineralny, efektywność bariery, pozycja bariery.

Introduction

The insulation system of oil-filled power transformers consists of a solid insulation – pressboard barriers and spacers, and insulating liquid - transformer oil. The use of paper and oil insulation results from the following reasons:

- Synergistic effect in puncture resistance of oil impregnated paper - dielectric strength of the paper-oil system is much higher than its components separately,
- The possibility of relatively easy isolation, with a complex geometry with an efficient cooling system.

The favourable effect of insulating barriers on the dielectric strength of fluids (gas or oil) gaps is well known for a long time and is used in many high-voltage devices, in particular in power transformers. According to the different results reported in literature, the insertion of a barrier between a sharp electrode (point, conic …) and a plane electrode immersed in fluid, improves the dielectric strength of oil gaps. The barrier acts as a geometric obstacle on the way of discharge development. Indeed, the injected charges at the sharp electrode accumulate on the surface of the barrier making the barrier to behave like a floating potential plane electrode. As a result, the electric field between the barrier and the flat electrode becomes uniform. Thus the insulation system will be divided into two parts: the space between the sharp electrode and the barrier (divergent electrodes system), and between the barrier and the flat electrode. Such a configuration also causes an increase in the length of the discharge path, and thus an increase in the dielectric strength of the oil gap [1-8].

Increasing the dielectric strength of the insulating system in the presence of barrier results from the impact of this latter on the discharge channel. The solid dielectric barriers immersed in oil exert polarizing forces on discharges (streamers) in proportion to the difference in electrical permittivity at the interface. It is assumed that the force acting on the discharge load results from the field's influence from the mirror charge on the barrier-oil interface, and is therefore proportional to the difference between the oil and the barrier material. If $\varepsilon_{barrier} > \varepsilon_{oil}$ electric forces direct the discharge load towards the barrier. If the $\varepsilon_{barrier} < \varepsilon_{oil}$, the surface charge (mirror) of the barrier repels the volume load of the streamer, regardless of the free charge sign [6].

Test Apparatus and Procedure

The experiments were achieved on a "Testing stand for high voltage insulation systems for renewable energy" financed by the Polish Science and Technology Fund. The system is equipped with a HV transformer (100 kV, 100 mA, 50 Hz), and an automatic voltage regulator; a cone-plate electrodes arrangement is used for tests.

The tested oil was a transformer oil based on the organic ester ENVIROTEMP® FR3. The insulating barrier was made of electro-insulating pressboard (dielectric constant ε_r = 3, electrical strength E_p = 25 kV/mm) with a thickness of 0.4 mm. Two types of barriers geometry were considered: circulars with a diameter of 40 mm (barrier B1), and rectangular with dimensions of 54 mm x 48 mm (barrier B2). The barriers were placed vertically, parallel to the flat electrode. The centre of the circular barrier coincided with the tip of the conical electrode. Two inter-electrode distances namely 2 and 2.5 cm were investigated. Figures 1 and 2 show the test cell and the dimensions of barriers, respectively.

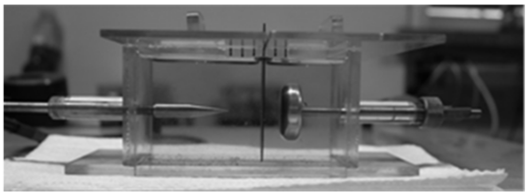


Fig.1. Measuring test cell with cone-plate electrode system and a barrier from pressboard

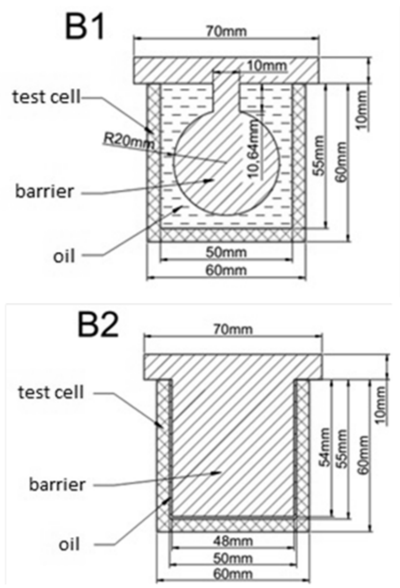


Fig.2. Shapes and dimensions of barriers (B1 and B2)

According to the standard [9], 50 Hz voltage was raised at 2kV/s, and the breakdown voltage is the average of 6 measurements. After each series of 6 measurements, oil sample was replaced by a fresh one. The state of the surface of barriers and electrodes were controlled after each measurement. The barriers were exchanged by new ones, each time perforation or traces of discharges are observed.

In the following, we define the effectiveness of barrier ζ by the ratio of the breakdown voltage of electrodes system with barrier U_{pB} to that without barrier U_{pBB}.

Results and discussion

The introduction of a pressboard barrier in the vicinity of sharp electrode into the inter-electrode gap significantly increases the dielectric strength of the system for both geometries of barriers as shown in Figures 3 and 4.

The effectiveness of barrier is the highest when it is close to the tip of the cone electrode (a/d=0) that is ζ = 1.72 to ζ = 2.06 for 2 and 2.5 cm gap, respectively. This is the optimal position. However, the closer the barrier is to the flat electrode, the lower the efficiency ζ of the barrier. The effectiveness of the barrier in the position a/d = 1 is the smallest and ranges from ζ = 1.04 to ζ = 1.10.

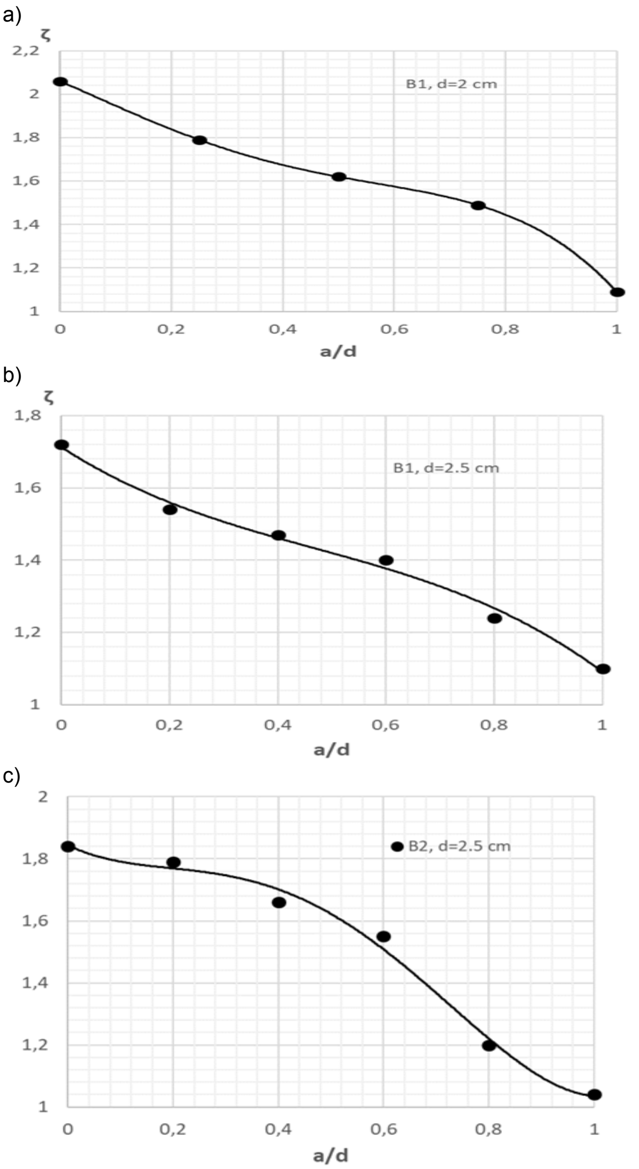


Fig.3. Barrier effectiveness for: a) barrier B1, d=2 cm, b) barrier B2, d=2.5 cm, c) barrier B2, d=2.5 cm

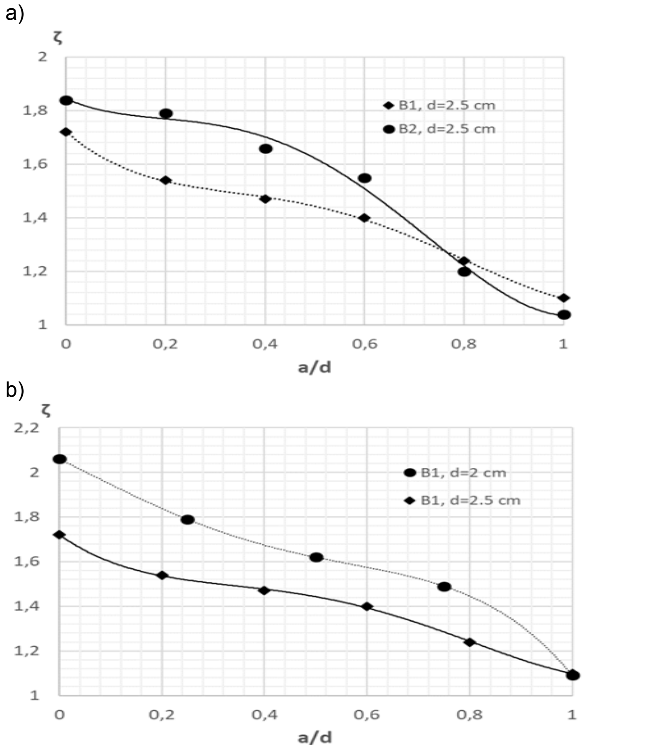
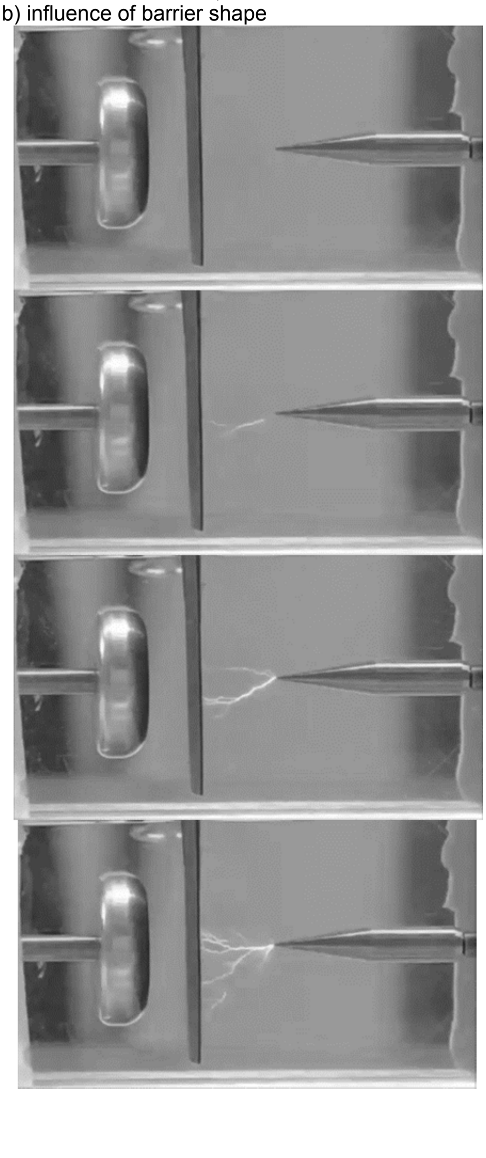


Fig.4. Barrier effectiveness: a) influence of distance for a circular barrier, b) influence of barrier shape



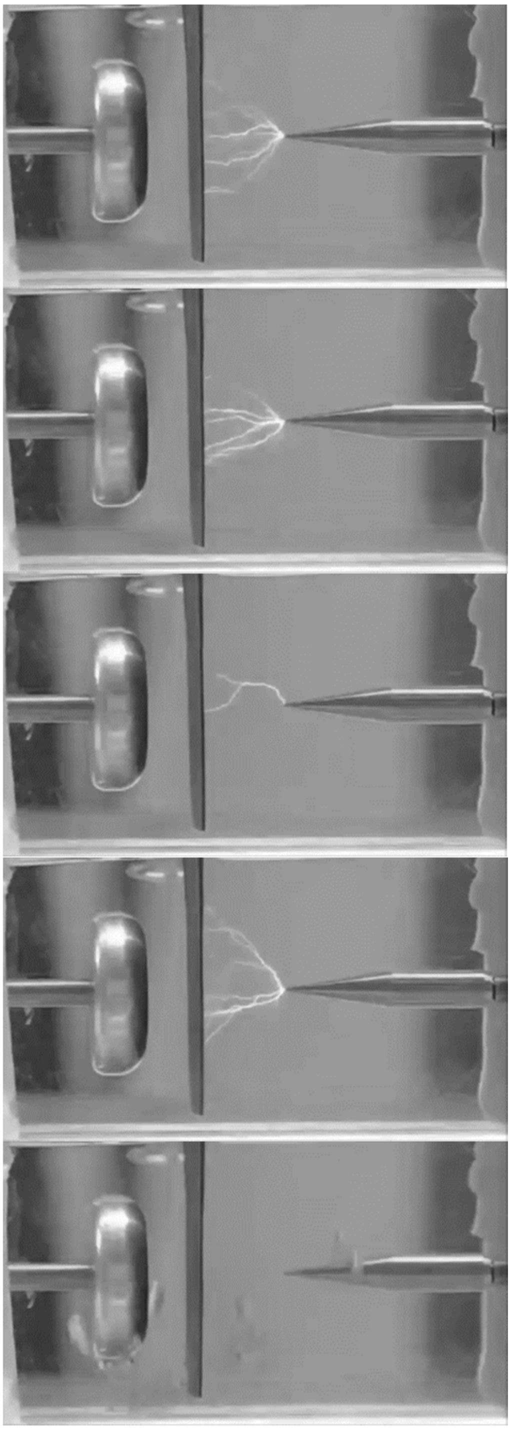


Fig.5. Registration of successive stages of the discharge development in oil gap with the barrier.

The obtained results confirm those reported elsewhere [6, 7] for mineral transformer oil and other kind of barrier insulating materials according which the optimal position of the barrier is 20% of oil gap (a/d=0.20) from the cone electrode. Note that Beroual el al [8] showed analytically that the optimum position of insulating barrier in a point – plane electrode system is at a distance $a=r_p/2$ from the point; r_p being the radius of curvature of the needle.

The pressboard inserted in the inter-electrode space constitutes a physical obstacle that deviates the trajectory of discharges/streamers leading to a significant increase of the dielectric withstand of the system. Indeed, the initiated streamers at the sharp electrode are blocked in their direct development toward the plane electrode; they are deviated as shown on Figure 5. They get around the barrier and then propagate from the edge of barrier till they reach the plane electrode resulting in breakdown. It happens that the discharges perforate the pressboard barrier. In that case, the breakdown occurs directly through the hole within barrier.

Summary

The influence of an insulating barrier on the electrical breakdown voltage of oil cone-plane electrodes gaps subjected to AC voltage depend on:

- Barrier position with respect to conic electrode,
- Geometrical dimensions of the barrier,
- The inter-electrode gap.

The position at which the barrier is the most effective is the one where it is placed very close to the conical electrode (i.e.; for a=0) whatever the electrode gap or the barrier sizes and shape.

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