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Study of the behavior of water droplets under the influence of a uniform electric field in epoxy resin samples having different wt% percentages of nanoparticles and microparticles

Zevgolas L*, Cheng Y**, Danikas M G*** and Sarathi R****

In this paper nanocomposite samples of epoxy resin and TiO_2 nanoparticles and microparticles were investigated with water droplets on their surface. Samples with 1 wt% nanoparticles, 1 wt% nanoparticles with 3 wt% microparticles, 3 wt% nanoparticles and also 3 wt% nanoparticles with 3 wt% microparticles were investigated. A uniform electric field was applied and the behaviour of the water droplets was observed. Parameters that were studied were the water conductivity, the droplet volume, number of droplets and the droplet positioning w.r.t. the electrodes. All above mentioned parameters influence the flashover voltage of the samples. It is to be noted that – at least in some cases – the water droplet positioning w.r.t. the electrodes was more important in determining the flashover voltage than the droplet volume. The results indicate that the addition of microparticles in a nanocomposite does not necessarily improve the flashover voltage behaviour.

Keywords: *Flashover voltage, surface discharges, nanocomposites, uniform electric field, water droplet, water conductivity*

1.0 INTRODUCTION

Epoxy resin is an insulating material widely used in various high voltage applications [1]. Traditional base polymeric materials improve their electrical thermal and mechanical properties when they are mixed with small percentages of nanoparticles [2, 3]. Interfaces between the nanoparticles and the surrounding polymer matrix play a most critical role [4].

Nanocomposite polymers present higher breakdown strength than their base counter parts [5]. Space charges distribution, thermal conductivity, electrical treeing resistance and Partial Discharge (PD) resistance are also improved in the case of nanocomposites in comparison with conventional polymers [6-10].

In this paper, epoxy resin with TiO_2 nanoparticles and microparticles was investigated. Samples with various wt% percentages in nanoparticles and microparticles were tested. The purpose of this work was to see how water droplets arrangements on the surface of such samples under the effect of uniform electric field affect the flashover voltage and also how the addition of microparticles to a nanocomposite affects the flashover behaviour. Parameters, such as water droplet conductivity, number of droplets, droplet volume and droplet positioning w.r.t. the electrodes were examined.

*Department of Electrical and Computer Engineering,Democritus University of Thrace,Xanthi, Greece.
**State Key Laboratory of Electrical Insulation and Power Equipment,Xi'an Jiaotong University, Xi'an, P. R. China.
***Department of Electrical and Computer Engineering, Democritus University of Thrace, Xanthi, Greece, mdanikas@ee.duth.gr.
****Department of Electrical Engineering, Indian Institue of Technology Madras, Chennai, India

2.0. WATER DROPLETS ON POLYMER SURFACES AND THE FACTOR OF HYDROPHOBICITY

Most polymeric materials used for outdoor and/or indoor applications have some sort of hydrophobicity, i.e. the capability of having discrete droplets on the insulator surface. Loss of hydrophobicity may result from surface discharges, pollution of the insulator surface and/or from ultraviolet radiation.

Generally speaking, when a water droplet is positioned on a nanocomposite surface (or for that matter on a polymer surface) under a high electric field parallel to the surface, discharges may appear and the surface tension may be reduced with the increase of temperature at the edge of the droplet. In this way, the droplet starts deforming and continuous discharges may ensue between the edges of the droplet and the electrodes, which will eventually lead to the final flashover [11]. It should be pointed out that the contact angle, as well as the PD inception voltage, depends on the percentage of nanoparticles in the nanocomposite [12].

3.0. EXPERIMENTAL ARRANGEMENT

The voltage was supplied from a 20 kV transformer. The dimensions of the electrodes are shown in Figure 1. The electrodes were made of copper and they are half cylindrical with rounded edges. No asperities were allowed on the electrode surfaces. They were positioned on the epoxy resin sample at a distance of 2.5 cm from each other. The aim of the experiments was to measure the flashover voltage with the different droplet arrangements at different conductivities.

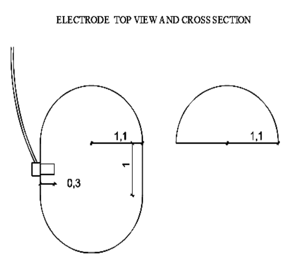

FIG. 1. TOP VIEW OF ONE OF THE ELECTRODES AND CROSS SECTION (ALL DIMENSIONS IN CM)

The water droplets were positioned on the sample surface with the aid of a special arrangement consisting of a metallic frame and three rules, one of which had two laser indicators. The water droplets were poured into the sample surface with the aid of a syringe. The droplet arrangements are shown in Figure 2.

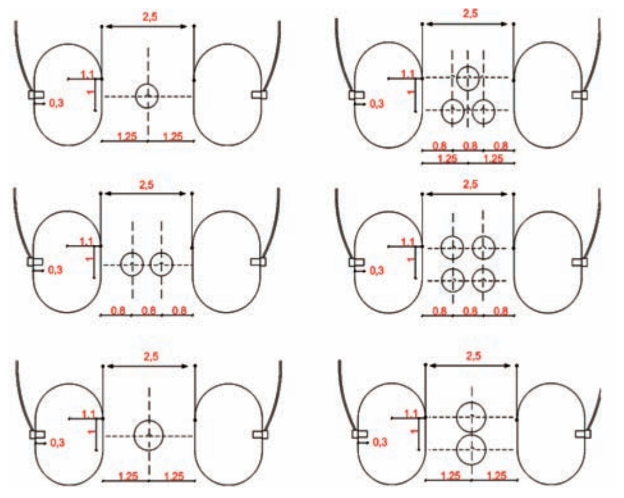

FIG. 2. DROPLET ARRANGEMENTS FOR THE EXPERIMENTS (ALL DIMENSIONS ARE GIVEN IN CM)

All dimensions are given in cm. The conductivities investigated were 1.4 μS/cm, 100 μS/cm, 200 μS/cm, 500 μS/cm, 1000 μS/cm, 2000 μS/cm, 5000 μS/cm and 10000 μS/cm. The conductivity measurements were performed with the aid of an electronic measuring device of conductivity of Type WTW inoLab cond Level 1 with a probe WTW Tetracon 325.

The following droplet arrangements were used: 1) one droplet of 0.05 ml volume each, 2) two droplets of 0.05 ml volume with a distance of 0.8 cm between their centres, 3) three droplets of 0.05 ml volume each, forming a triangle, 4) four droplets of 0.05 ml each, 5) one droplet of 0.1 ml volume at a distance of 1.25 cm from the electrodes and 6) two droplets of 0.1 ml each at a distance of 1 cm from each other and 1.25 cm from the electrodes.

The surface roughness of the samples was measured with the aid of a device Perthen Type Perthometer M4P. Surface roughness for the epoxy nanocomposite samples of 1% wt nanoparticles was 0.28 μm, for the epoxy nanocomposite with 1 wt% nano- and 3 wt% microparticles was on average 0.02 μm, for the nanocomposite samples with 3 wt% nanoparticles was 0.3 μm and for the nanocomposite with 3 wt% nano- and 3 wt% microparticles was 0.11 μm.

After positioning the droplets on the epoxy resin surface, the voltage was slowly raised until flashover occurred. After that and after cleaning the surface and positioning new droplets on it, the voltage was raised up to the previous flashover value minus 1.2 kV, so that no new flashover would occur. At this voltage value, the arrangements could stay for 5 min. If no flashover occurred, the voltage was raised by 0.4 kV and the procedure was repeated until flashover occurred. The new flashover value was recorded. The reason for allowing the voltage for 5 min at each voltage level was because a certain time was required for the droplets to deform and for the PD to start.

4.0. EXPERIMENTAL RESULTS AND DISCUSSION

In Figures 3 - 6 the experimental results with the various droplet arrangements, the different water conductivities and droplet volumes are given.

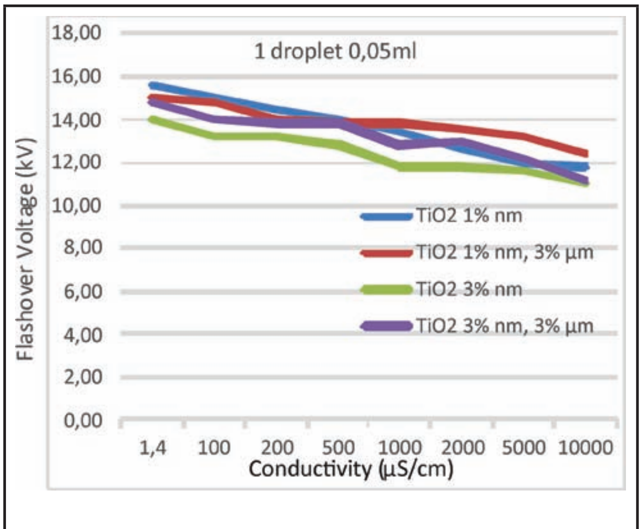

FIG. 3. COMPARISON OF THE INSULATING MATERIALS – ARRANGEMENT OF 1 DROPLET (VOLUME 0.05 ML)

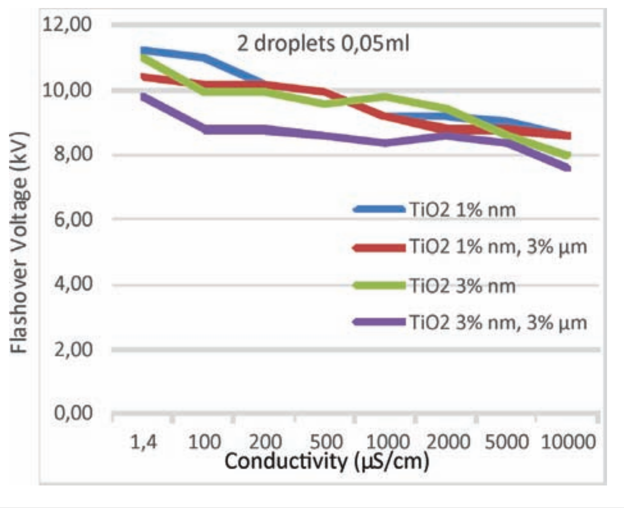

FIG. 4. COMPARISON OF INSULATING MATERIALS – ARRANGEMENT OF 2 DROPLETS (EACH OF VOLUME 0.05 ML)

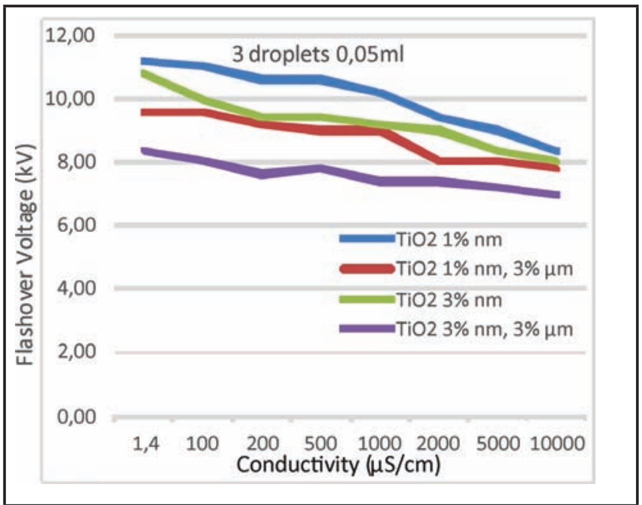

FIG. 5. COMPARISON OF INSULATING MATERIALS – ARRANGEMENT OF 3 DROPLETS (EACH OF VOLUME 0.05 ML)

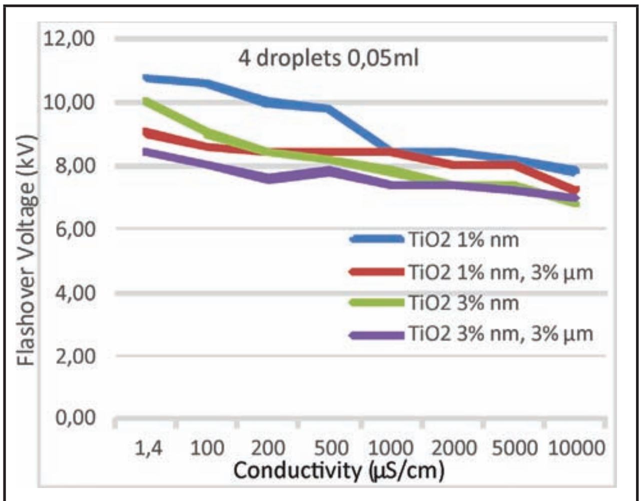

FIG. 6. COMPARISON OF INSULATING MATERIALS – ARRANGEMENT OF 4 DROPLETS (EACH OF VOLUME 0.05 ML)

During the experiments, it was observed that some times the flashover voltage was due to the first break up of the droplet, i.e. it was not possible to observe the gradual break up of the droplet(s) while increasing the applied voltage. This was particularly observed with the arrangements of 2, 3 and 4 droplets. On other occasions, the droplet(s) started deforming at about 0.4 to 1.2 kV before the actual flashover voltage.

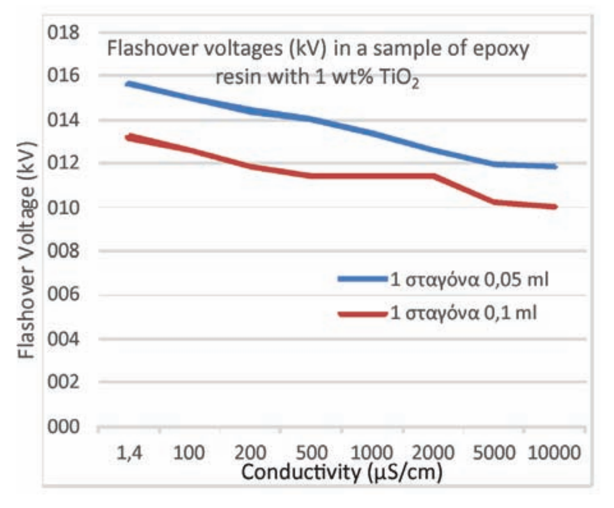

FIG. 7. COMPARISON OF FLASHOVER VOLTAGE WITH DROPLETS OF 0.05 ML AND 0.1 ML IN A SAMPLE OF EPOXY RESIN WITH 1 WT% TIO_2.

As is seen from Figure 7, it is evident that the droplet volume affects the flashover voltage. The number of droplets also affects the flashover voltage (as seen from Figures 3 - 6). The distance of the droplets from the electrodes is another factor influencing the flashover voltage, where experiments with two droplets of 0.05 ml each gave lower flashover voltages than the ones with one droplet of 0.1 ml, the reason being that the distance with the two droplets from the electrodes was 0.8 cm whereas in the arrangement with one droplet of 0.1 ml the distance from the electrodes was 1.25 cm [13]. Figures 3 - 6 indicate that the lesser flashover voltages were noticed with epoxy resin with 3 wt% of nanoparticles and with 3 wt% microparticles. This is shown clearly with 3 and 4 droplets, less clearly with 2 droplets, whereas with 1 droplet things are a little bit blurred. Kozako et al. [14, 15] gave an explanation as to why nanocomposites have a better flashover behaviour than their conventional counterparts, suggesting that – because of the gradual erosion of the surface – nanoparticles come to the surface and somehow hinder the propagation of the flashover. Not much experimental evidence was presented until now as to the behaviour of materials with an admixture of nano- and microparticles. It seems, however, that – for this specific epoxy resin and for the specific added particles of TiO_2 – an increasing percentage of nano- and micro-particles does not necessarily increase the flashover voltage. Further experimental investigations in this direction are necessary in order to clarify the relation between the flashover voltage and the various percentages of nano- and micro- particles.

The idea of having various droplet arrangements (Figure 2) was to indicate the influence of the number of droplets as well as their positioning w.r.t. the electrodes on the flashover voltage. From the results presented in this paper, it is evident that there is an effect of both the number of droplets as well as of their positioning on the flashover voltage. TiO_2 nanoparticles and microparticles with epoxy resin were chosen since there was previous work done with the same nanocomposite, that work, however, was concerned mainly with charging phenomena, and especially charging phenomena below the inception voltage [16]. The choice of adding nano- and micro-particles in epoxy resin was also related to the work performed in [16], i.e. there was an effort to see the effect of added nano- and micro-particles on the minute charging phenomena as well as on the flashover voltage. Regarding the quantification of the improvement of the flashover voltage, it seems that the epoxy resin with 3 wt% nano- and 3 wt% microparticles is doing relatively worse than the other samples, especially for the 2, 3 and 4 droplet arrangements, with the situation being a bit more uncertain with the 1 droplet arrangement. Further data is needed in order to fully quantify the differences between the various droplet arrangements. In the context of this work, nano- and microparticles were added [2]. No millimeter sized particles were added in the samples. An interesting point that can be raised is that of the influence of the contact angle of the water droplets and their change with the experimental conditions. Such a change is expected but no results can be reported at this stage. Certainly, we intend to do this in our future work, since it is expected that the uniform electric field and water conductivity may exert an influence on the contact angle.

5.0. CONCLUSIONS

In this paper, experimental data were presented regarding the flashover behaviour of epoxy resin having nanoparticles and/or microparticles of TiO_2. Parameters, such as water conductivity, number of droplets, volume of droplets, distance of droplets from the electrodes, play a vital role in determining the flashover voltage. The addition of nanoparticles improves the flashover voltage up to a certain percentage. The addition of both nano- and micro-particles needs further clarification in order to reach definite conclusions.

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