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Classification of Discharges Initiated by Liquid Droplet on Insulation Material under AC Voltages Adopting UHF Technique

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Abstract**—**In the present work, an attempt has been made to understand the feasibility of using UHF technique for identification of any corona discharges/ arcing in insulating material due to water droplets. The sensors of broadband type are useful for identification of such discharges. It is realised that arcing initiated by liquid droplet radiates UHF signals in the entire bandwidth up to 2 GHz. The frequency content of the UHF signal generated due to corona/arcing is not much varied in epoxy nanocomposites with different weight percentage of clay content. The exfoliated/intercalated properties were analysed through TEM studies. It is realized that corona initiated discharges are of intermittent process. The hydrophobicity of the material characterized through contact angle measurement. It is realized that low Wt % of nanoclay content in epoxy resin reduces the surface carbonization due to arcing/corona discharges. The results of the study with gamma irradiated specimen indicates that contact angle, discharge inception time and evaporation time of the liquid are much lower than the virgin epoxy nanocomposite material.

Keywords**—**Arcing, Corona, epoxy resin, insulation, nanocomposites, UHF signal,water droplet.

I. Introduction

NANOCOMPOSITES are emerging as a new class of insulating materials for demanding application in all electrical equipment used in the outdoor/indoor power system network [1,2]. Polymeric insulators are preferred because of their better dielectric properties, low surface energy which maintains a good hydrophobic surface, better pollution performance in outdoor service condition, low weight, easy handling, vandal resistance, and cost effectiveness [3]. Recently, epoxy resin with organically modified clay filler has been used in major applications [4-8]. The selection of clay as a reinforcing material in epoxy resin is extremely appealing because of the cost, high thermal inertness, and environmentally friendly characteristics. It is believed that consistent improvements in the properties of clay loaded polymeric systems can be achieved by minimizing clay aggregation, promoting the formation of chemical bonds between polymer and clay and achieving exfoliation of clay.

Yong Zhu et al., studied the electrohydrodynamic activity of water droplet in silicone rubber insulation [9]. They have demonstrated that a locally high electric field at the tip of the droplet can trigger corona discharges. S.W. Rowland et al., studied discharges between water droplets on silicone rubber insulation surface under AC voltages [10]. They have concluded that the discharge process depends upon the magnitude of discharge current, resistivity of the moisture and the hydrophobic level of the insulation surface. It is essential to identify such discharges at the surface of the insulting material/insulators, at the incipient stage, to avoid any major catastrophic failure. Suda etal., established a method of monitoring wheather flashover occurs or not in a string insulator based on leakage current waveforms and their frequency characteristics [11]. Lopes et al., studied partial discharge activity from water droplet on a silicone rubber surface under AC voltage and concluded that electrostatic forces can change the droplet shape and spread them in the field direction. Also they have suggested that measurement of partial discharge can provide the surface hydrophobic condition of the insulating material [12].

Partial discharges often precede arcing and can cause severe damage to insulation of the power equipment [13]. The generated incipient/partial discharge current pulses are with rise and fall times of few nano seconds, signals of UHF range, (300-3000MHz) are excited [14,15]. The UHF method of identification of faults is basically a non-destructive technique and can identify active defects present in the insulation during operation [16,17]. Considerable research works were carried out on PD activity in transformer oil insulation [18-20]. Understanding the corona/surface discharges in out door insulation material, adopting UHF technique, is at infancy stage. Having known all this, in the present work, a methodical experimental study was carried out to understand the feasibility of using UHF technique to identify corona/surface discharges in an insulating material initiated due to water droplet. Also the impact of exfoliated/intercalated characteristics of epoxy nanocomposite material, to surface discharges/corona was analysed. The hydrophobicity of the material characterized through contact angle measurement. The exfoliated/intercalated properties were analysed through TEM studies.

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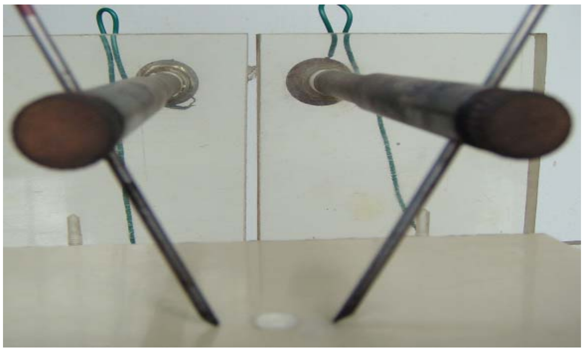

Fig. 1 Test Electrode Arrangement

II. Experimental Studies

Epoxy nanocomposites were synthesized by high speed mechanical shear mixing of organo clay in the resin bath at room temperature. The clay mineral used in this study was organophillic MMT clay, procured from southern clay products Inc. (Gonzales, Texas) under the trade name of garamite 1958. Table I shows the physical properties of Garamite 1958 [21]. After uniform mixing of clay particles in epoxy resin (DGEBA, CY205, Ciba Geigy Inc), Tri Ethylene Tetra Amine (TETA) hardener was added and then cast in a mold of required dimension. Epoxy nanocomposites with different percentage of clay in the range 1-10 wt%, were prepared. Ultra thin films with thickness of about 80nm for TEM observation was prepared by cutting the specimen using a glass knife with Leica ultracut UCT microtome. The sections were collected on carbon coated copper grids and kept in a desiccator before TEM studies (CM-12 Scanning transmission electron microscopy) to examine the morphology. The epoxy nanocomposite materials were exposed to gamma irradiation with a dose rate of 450 kRads/h. In the present study the specimens were exposed to 2000 kRads and 5000 kRads.

TABLE I
PROPERTIES OF CLAY PARTICLE

Colour	Off White
Bulk Density g/cc	1.5-1.7
Weight loss at 1000°C	37%
D spacing at d_{001}	17.2

The test electrode setup used for investigating the behaviour of water droplets in an quasi uniform electric field is shown in Fig. 1. The Quasi uniform electric field gap consists of two angular electrode tip cut for 45˚ (with edges smooth) placed on 3mm thick epoxy nanocomposite material. The electrodes are separated by a gap distance of 15mm. One electrode is connected to the AC high voltage source and the other electrode connected through a resistance of 1kΩ to ground. The applied AC voltage measured using high AC voltage probe (LeCroy, USA model No.PPE20kV). The potential drop across the resistance fed directly to the digital storage oscilloscope to measure the discharge current characteristics. A 20 µl distilled water and 0.1N NH_4Cl droplet of conductivity 2500 µS/cm were used for the discharge study. The AC voltage applied at the rate of 300V/s till the discharge initiates between the droplet and the electrodes. The NH_4Cl is used as standard solution (as suggested in IEC-60 587) while carrying out tracking test to understand the surface condition of insulation due to discharges [22]. Based on the test, level of decomposition of the material could be understood under polluted condition. The sensor used in the present study is a broadband type sensor, which is placed at a distance of 20cm away from the test cell. The output of the UHF sensor connected to the spectrum analyzer/high bandwidth digital storage oscilloscope. The UHF signals were captured using a real time digital storage oscilloscope (LeCroy four channel digital real time oscilloscope, 3 GHz bandwidth, operated at 20 GSa/s) with an input impedance of 50 ohms. The droplet movements were photographed with Sony digital camera by operating it in movie mode (model No. DSC T100).

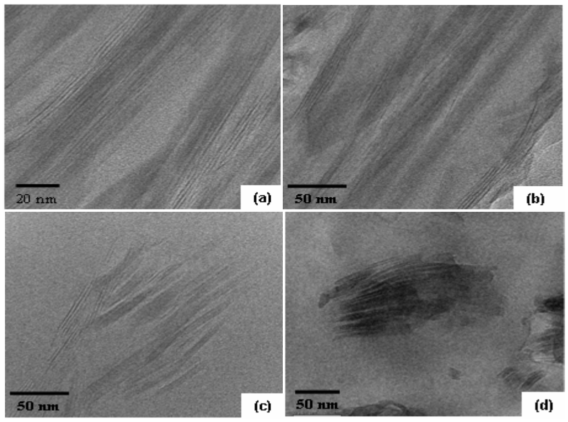

Fig. 2 TEM Patterns of Epoxy Nanocomposites (a) 1% clay (b) 3% clay (c) 5% clay (d) 10% clay

III. Results and Discussion

A. Analysis of Morphology of Epoxy Nanocomposite Material

Fig. 2 shows the TEM images (showing intercalated/exfoliated structure) of the epoxy nanocomposites. The thick dark lines are the cross-section of the clay layers and grey white portions are the epoxy resin material. It is observed that the prepared specimens are intercalated with partial exfoliation (Fig.2a,b,c). From Fig.2d, it is realized that, as the weight percentage of clay is increased to 10%, agglomeration occurs. In an exfoliated structure, the layers of the clay have been completely separated and oriented in random in the base matrix [5].

B. Analysis of Hydrophobicity Level of Nanocomposites using Contact Angle Measurements

Contact angle measurements are an indication of the hydrophobicity of the material. If the contact angle of the material is above 90^0, it is the indication that the material is

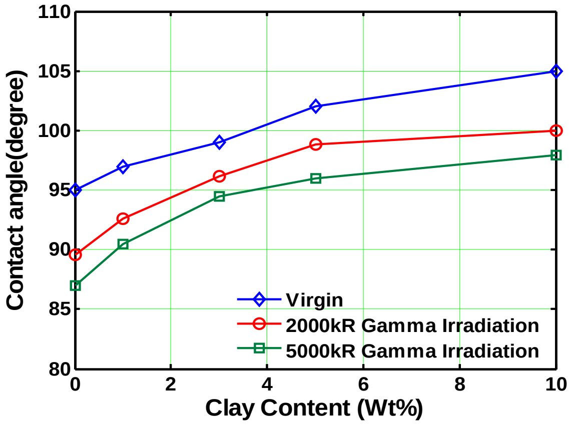

Fig. 3 Variation in contact angle of epoxyu nanocomposites

hydrophobic and if the value is less than 90^0 it is the indication that the material is hydrophilic. In the present work, the static contact angle was measured by liquid droplet method using distilled water[23]. The size of the drop was about 1.5mm in diameter. The contact angle was measured using the following equation,

$$\theta = 2 \tan^{-1}\left(\frac{2h}{d}\right) \quad (1)$$

where d is the diameter of the liquid drop and h is the height of the liquid drop. After the solution is placed over the surface of the specimen, the height and diameter of the liquid droplet were measured within 5 seconds. For each specimen, the contact angle was measured at six different locations and averaged. Fig. 3 shows variation in contact angle of the epoxy nanocomposites and for gamma irradiated specimens. It is realized that contact angle increases with increase in percentage of clay in epoxy nanocomposites, in the range studied. It is well known that increase in contact angle of the specimen reduces the wettability of the surface. It is observed that for a gamma irradiated specimen, increase in dosage shows reduction in contact angle of the specimen.

C. Understanding the Discharge Mechanism Due to Water Droplet

When a droplet of water is placed in a strong electric field, it deforms to form a conical shape. The deformed water droplet will disrupt by the interaction of electrostatic force with the surface tension of the droplet, thereby a fraction of the droplet are ejected from the tip of the cone initiating corona discharges. In the present work, the discharge inception voltage measured as voltage at once the transient discharge current is observed.

When an AC field is applied to liquid droplet, the shape of the droplet deforms with time depending on the frequency of the applied voltage. However, the droplet deforms strongly only at a particular frequency [10]. Electric field intensification along the triple point junctions of the insulation/air/water droplet contributes towards the liquid droplet deformation along the insulator surface and initiates discharges. The droplet of water placed on the surface of the insulating material and energized, it experiences tangential force, therefore the water droplet gets elongated along the surface. Fig. 4 shows typical variation in discharge inception voltage when droplet of water of different conductivity, placed in the electrode gap over nanocomposite material, under AC voltages. It is realized that increase in percentage of clay in nanocomposite shows reduction in discharge inception voltage up to 3 wt% of clay and above which slight increase in discharge inception voltage is observed. Comparing the discharge inception voltage with distilled water and the ammonium chloride solution, it is realized that discharge inception voltage is high with water droplet of high conductivity. Fig. 5 shows typical current signal measured during the discharge process. It could be realised that based on the magnitude of current signal, the evaporation time of the liquid varies. In the present study 20MΩ is used as current limiting resistor.

To understand the surface condition of the insulating matetrial, after the discharges, the droplets were allowed to evaporate by applying voltage of 16 kV. Fig. 6 Variation in evaporation time of liquid droplet stressed under AC voltage with epoxy nanocomposites aged with different dosage of gamma irradiation It is realized that the time for evaporation is high with epoxy nanocomposites up to 3 wt% of clay above which considerable reduction in evaporation is observed. Also by comparing the evaporation time of the droplet with distilled water and the ammonium chloride solution, it is realized that evaporation time is less with ammonium chloride solution.

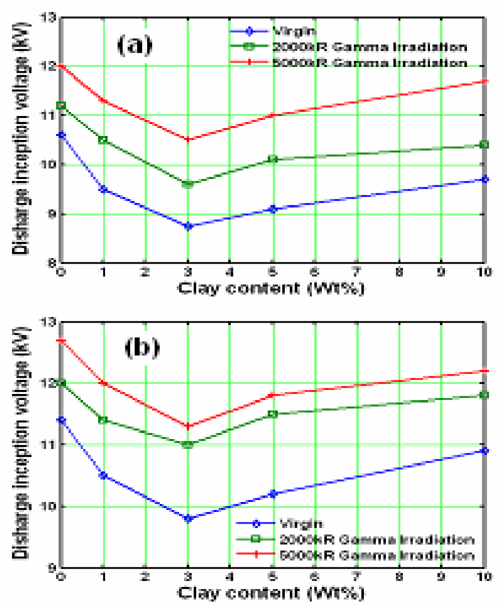

Fig. 4 Variation in Discharge inception voltage with epoxy nanocomposite aged with different dosage of gamma irradiation (a) distilled water (b) 0.1N ammonium chloride solution

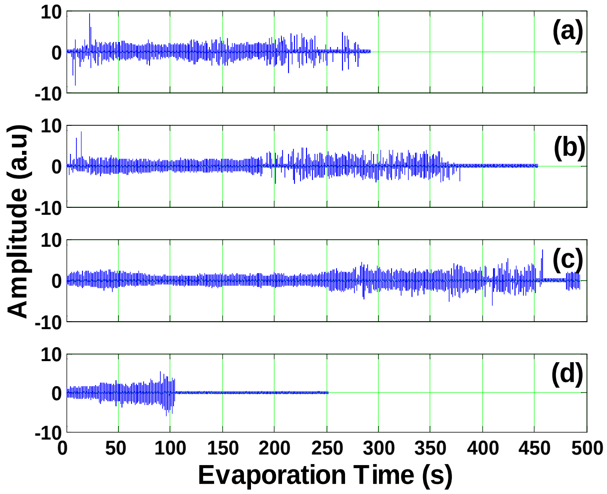

Fig. 5 Typical current signal measured during experimental study with ammonium chloride solution. (a) 20 µl (b) 30 µl (c) 60 µl solution with 20 MΩ current limiting resistor (d) 60 µl solution with 10 MΩ current limiting resistor

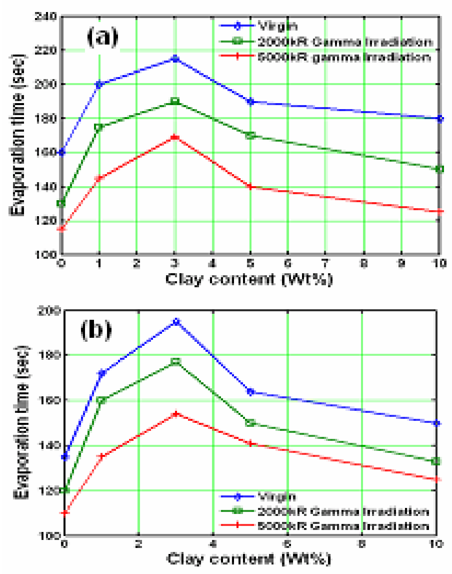

Fig. 6 Variation in evaporation time of liquid droplet stressed under AC voltage with epoxy nanocomposites aged with different dosage of gamma irradiation (a) distilled water (b) 0.1N ammonium chloride solution

In general, when the droplet is placed in a high electric field zone, corona discharge occurs and the surface tension becomes lower with the increase in temperature (due to corona discharges) at the edge of water droplet, tending to zero at the discharge root. The water will protrude from the drop at the discharge root causing continuous discharges between the water droplets and the edges of two electrodes as shown in (Fig. 7). The voltage and current measured at the instant of corona formation and during continuous arcing/discharges is shown in Fig. 8a and 8b respectively. When the two electrodes are bridged by water droplet forming thin film only the resistive current flows and could be realized from Fig. 8c.

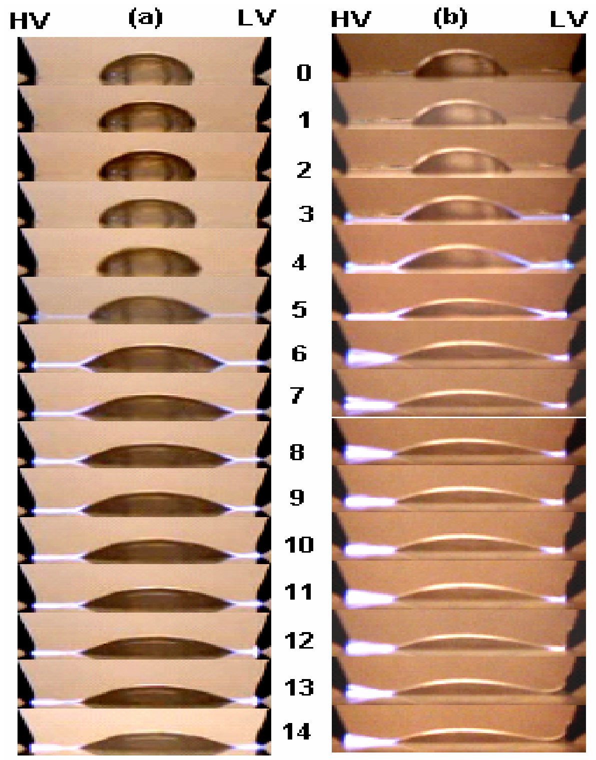

Fig. 7 Typical photograph showing arcing between electrode s and water droplets (a) 1 Wt% (b) 10 Wt% of clay in epoxy nanocomposites

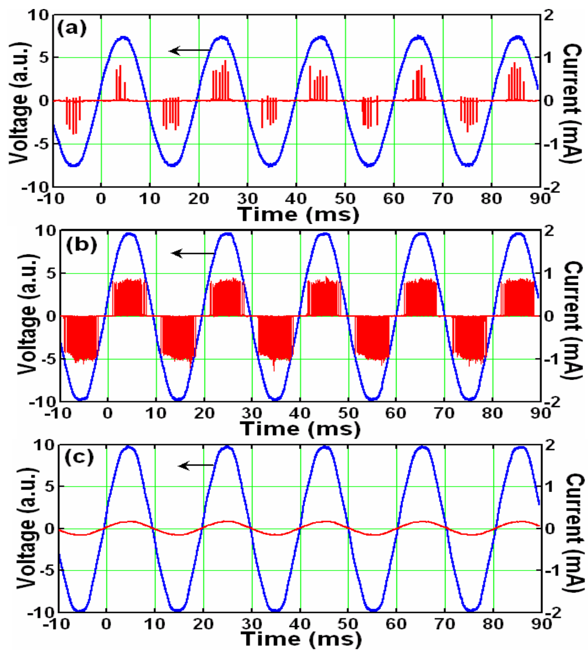

Fig. 8 Typical voltage and current measured at different instant of time (a) corona inception (b) during arc discharge (c) resistive current flow due to bridging of electrodes

D. Influence of Gamma Irradiation on Surface Condition of Insulating Material

It is realised from Figs. 4 and 6; increase in doasage of gamma irradiation shows increase in discharge inception voltage and reduction in evaporation time. The condition is the same with the distilled water and ammonium chloride solution. It could be realised by comparing the static contact angle of the insulation surface with the discharge inception voltage, it shows inverse relationship upto 3 wt%.

E. Influence of Current Limiting Resistor on the Evaporation of Liquid Droplet

In the present study for a constant volume of liquid droplet, under AC voltage, the evaporation time is about 600s with 20 MΩ resistance and about 200s with 10MΩ resistance in the circuit. It is realised that increase in value of current limiting resistor shows increase in evaporation time and the surface damage that occurs during evaporation process is minimum. The typical variation in magnitude of current flow due to variation in current limiting resistor is shown in Fig. 5c and d. Higher the magnitude of current flow cause carbonization of surface. Fig. 9 shows typical damage that occurred at the surface of the insulating material with different values of current limiting resistors. This indicates directly the magnitude of leakage current/surface discharge current/arcing current play a major role on the damage of insulating material.

F. Analysis of Discharges through UHF Technique

Fig. 10 shows typical time domain and the corresponding normalized frequency content of the signal measured at the time of continuous discharge between the droplet and the electrodes. It could be realized from the frequency response analysis that UHF signals are generated in the range upto 2 GHz. It is observed that the frequency content of the UHF signal generated due to corona is bandlimited to 500 MHz.

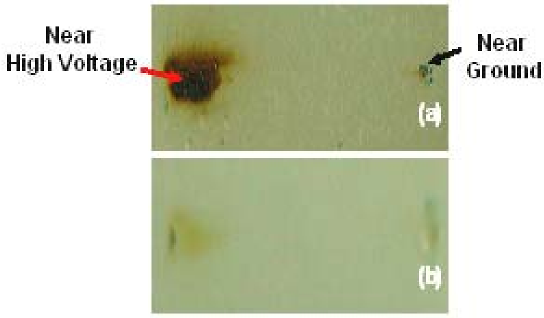

Fig. 9 Typical erosion structure observed with different current limiting resistors (a) 10 MΩ (b) 20MΩ

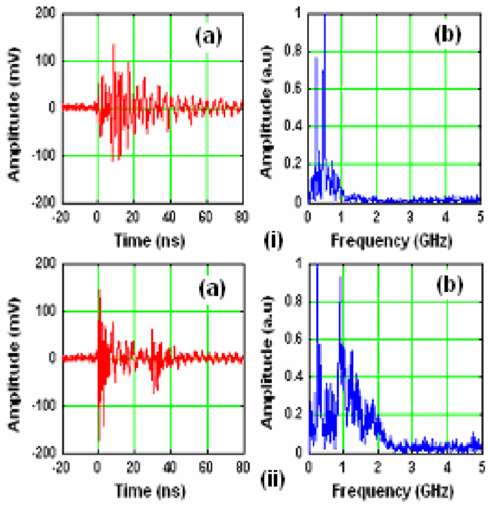

Fig. 10 Typical (a) time domain and (b) frequency domain analysis of UHF signal generated due to discharges initiated from water droplet (i) corona discharge (ii) arcing between droplet and electrode

IV. Conclusion

The important conclusion arrived at based on the present study are the following:

1. High speed mechanical shear mixing techniques allows one to form exfoliated nanocomposite structure. This could be realized based on the TEM studies. The contact angle of the insulating material shows increase with increase in percentage of clay in epoxy nanocomposite.
2. Increase in percentage of clay content in epoxy resin shows reduction in discharge inception time up to 3 wt% . The evaporation of volume of liquid shows increase in time with increase in percentage of clay content of upto 3 wt%. Also it is observed, increase in volume of the droplet shows increase in evaporation time, irrespective of conductivity of the liquid.
3. It is realized that gamma irradiated specimen shows reduction in contact angle compared to virgin specimen. It is also observed increase in gamma irradiation dosage shows complete reduction in contact angle. The discharge inception voltage of the gamma irradiated specimen is high compared to virgin specimen. The evaporation time of the liquid droplet placed over gamma irradiated specimen shows reduction in its value compared to virgin specimen.
4. The magnitude of current flowing during discharge process have major impact on surface carbonization of epoxy nanocomposite.
5. It is realized that arcinginitiated from liquid droplet on the surface of epoxy nanocomposite insulating material radiates UHF signal in the entire bandwidth upto 2 GHz. The UHF signal generated due to corona bandlimited to 500MHz.

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