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Simulations of the Propagation of Streamers in Electrical Discharges in a 5mm Water Filled Gap

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Abstract

This work is devoted to the modeling of streamer discharge, propagation in liquid dielectrics (water) gap using the bubble theory. This of the electrical discharge (streamer) propagating within adielectric liquid subjected to a divergent electric, using finite element method (in two dimensions). Solution of Laplace's equation governs the voltage and electric field distributions within the configuration, the electrode configuration a point (pin) - plane configuration, the plasma channels were followed, step to step. That shows the streamer discharge bridges the dielectric liquid gap and indicates the minimum breakdown voltage required for a 5mm atmospheric pressure dielectric liquid gap as 22KV. The initiated streamer grows and branches toward all elements that satisfy the required conditions. The electric potential and field distributions shown agreement with the streamer growth, according to the simulation development time.

Keywords: Herbal; Phytochemical; Cytotoxic; Formulations

Introduction

The breakdown of insulating liquids is not simple to explain and the mechanism responsible for the initiation of breakdown is still open to controversy. Many breakdown theories have been put forward since the start of research on this subject. Experimental data on the electric breakdown of liquids that were accumulated, confirm that there are several different breakdown mechanisms that cannot be described in the context of a unified theory [1-4].

The ignition of an electric discharge in the liquid phase leads to the generation of non-thermal plasma, which can be utilized in various processes and technologies. An application of high electric energy into the system initiates an intensive movement of charged particles resulting in frequent collisions [5,6]. The discharge generation depends on the environment in which the plasma is ignited. There are at least three main factors distinguishing the liquid phase from gasses. The first one is a substantially higher density inducing a higher collision frequency and low mobility of charged particles. The second problem appearing in aqueous solutions comes up from a high polarity and dielectric strength of liquid molecules. These properties lead to the creation of dipole momentum in the applied electric field, and cause inhomogeneous areas in the vicinity of an electrode surface. The third factor influencing the discharge creation in the liquid phase is a presence of ions and their different mobility in a solution. In particular, fast electrons and slow, heavy ions alter the propagation of discharge channels [7-9].

Kao [10] derived a mathematical model of the breakdown mechanism based on the formation of gas bubbles in liquids. He assumed that bubbles might be formed in a liquid for the reasons such as, the gas which accumulates in microscopic cavities and hollows on the electrode surface. From the liquid itself by local evaporation on the surface of the electrodes due to the action of electrical current, dissociation of molecules through collisions with electrons or impurities. Due to electrostatic forces overcoming the surface tension. The electrostatic force effect causes elongation of the bubble in the electric field. The streamer mechanism in liquids occurs if the electric field is strong enough, it is assumed that electron avalanches can initiate in the liquid [11].

This paper is aimed at the modeling of the streamers propagating within a dielectric liquid (water) submitted to a divergent electric field (point-plane electrode configuration). The aim is to determine the initiation propagation and branching of streamers in this liquid gap (water).

Principles of the Model

Many theories have been put the initiation the growth of a streamer in dielectric liquid [10,12-17]. Confirm that there are several different breakdown mechanisms that cannot be described in the context of a unified theory [2,18].

This model, here, was built based on several assumptions to initiating the growth of a streamer within the buffer liquid. Many conditions have suggested to the start and growth of the streamer.

Following are the basic assumptions of the proposed model:

The simulation was implemented in the two dimensional region of finite elements. Some nodes of some elements represent the electrodes, while the others represent the dielectric liquid between the electrodes.

The electric potential at all nodes of all elements that belongs to the dielectric is calculated by solving the Laplace equation with the boundary conditions on the electrodes and the streamer discharge pattern.

The likelihood of initiation and growth of a streamer can be satisfied when

The local electric field (in the center of finite element) is greater that a threshold value [19]. The local electric field will be calculated according to the values of the voltage at the nodes of each element. Also, The heat of liquid evaporation (Ws) is greater than the latent heat (L) [1,20].

$Ws = R\ s\ Is^2\ \Delta\tau$……………………………….(1)

Also

$L = \rho\ .Vab\ .Cp\ (T).\Delta T$……………………..(2)

When R_s is resistance streamer, I_s is current streamer, $\Delta\tau$ time duration of

jump, L is the energy to heat liquid [J], ρ is the mass density liquid(kg/m3),

Vab is the Volume of bubble [m3], $C_p(T)$ is the heat capacity of liquid (J/kg.K)

and ΔT is the temperature change (K).

The electric field value (E_{tip}) at the streamer tip is greater than a threshold value [21].

$E_{tip} = 2V_0/(r_0 \ln 4(d-l_s/r_0\ )$……………………(3)

Where V_0 is the applied voltage, d is the gap length and ls is the length of the streamer channel and r0 is the radius of the streamer channel.

The electric field of the bubble (E_b) is greater that a threshold value [22].

$$E_b = \frac{(3\varepsilon_r)/}{(2\varepsilon_r+1)\ E_{lo}} \text{ ………………………….(4)}$$

When E_{loc}. is the local electric field and ε_r is the relative permittivity of the dielectric.

All the streamer branches were followed for one step only, because they, at all conditions, will decay. And only the main will bridge the gap between electrodes.

Simulation and Results

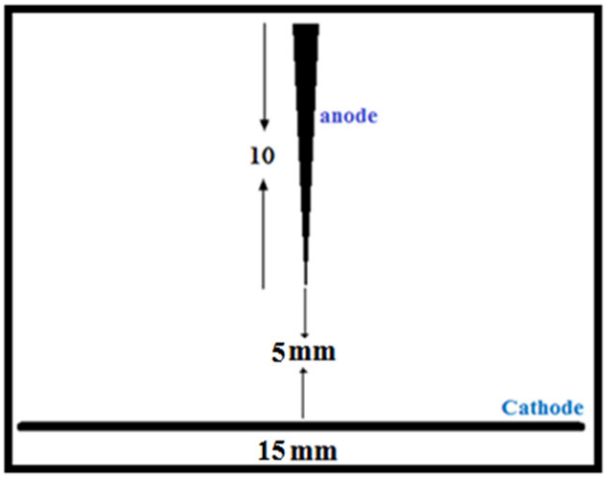

Figure 1: Longitudinal cross section of pin - plane configuration.

To validate our model, (Figure 1) consider a pin-plane electrode geometry, submerged in an insulating (water) of permittivity 78.6 and submitted to different applied voltages, the radius of streamer channel r_0=5μm and the conductivity of channel =0.1$(\Omega.m)^{-1}$. The model to be implemented, a computer simulation must be executed within a pin-plane electrode arrangement, Figure 1. The pin (anode) is of 10mm length. The plane (cathode) is about (15) mm diameter, and the distance between the electrodes is the liquid gap length of 5mm. A positive DC high voltage was applied to the pin (V0=22, 25, 27, 30 and 33kV) while the plane was grounded.

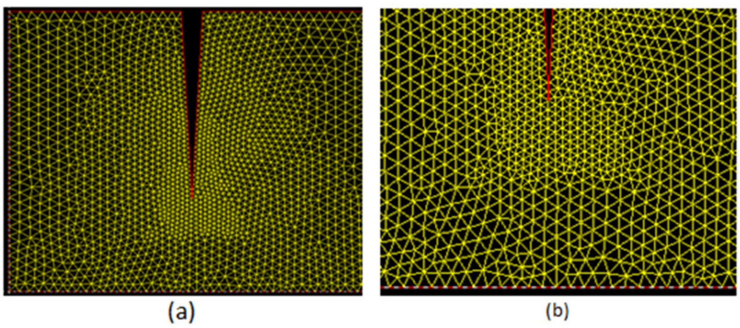

Figure 2: The grid for the pin - plane arrangement, a) a complete grid for the longitudinal cross section of the configuration, b) enlargement of the region around the tip of the pin electrode.

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Laplace's equation governs the voltage and electric field distributions within the arrangement. So, finite element method (in two dimensions) was used as a good tool to solve Laplace's equation in the complicated arrangement (the solution region as in Figure 2). The program was written with Fortran 77 language. It was used to do the calculations that are needed to predict the voltage and electric field distributions within the water gap between the electrodes (Figure 2). As well as and to simulate the path and branching of the streamer within the simulation area.

The Results

The simulation was carried out within the electrode arrangement of a water gap of 5mm length to show the initiation and growth of the streamer from the anode (pin) to the cathode (plane). The aim is to determine the breakdown voltage of the water gap, show the streamer branching and the effect applied voltage v_0 on the branching streamer and the time ($\Delta\tau_{arr}$) required to arrive the plain pole.

The streamer development between the electrodes

The streamer initiation and development was followed within the solution region between the two electrodes. A streamer is initiated at the elements that have values that consensus with the conditions; First, the local electric field is greater than the threshold value (7.4KV/mm) [23] and the energy injected by the electric field is sufficient to cause the evaporation of the liquid then formation the bubble [1,18]. Second, the electric field wit in the bubble is greater than the threshold (10kV/mm) [19], the last condition the electric field at the head streamer greater than the threshold (200kV/mm) [24,25].

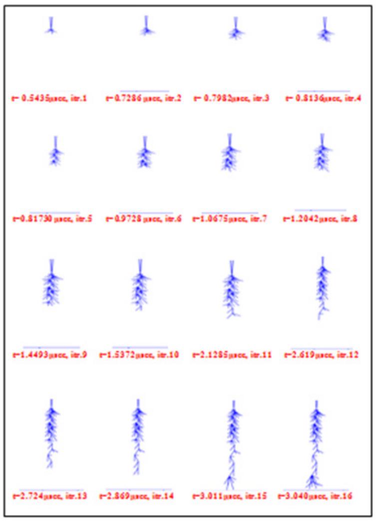

Figure 3: The streamer development with the time within pin-plane configuration in water with an electrode gap of D=5 mm, and applied voltage of V=22 kV.

The gap breakdown voltage was expecting at the minimum applied voltage value that grows streamer pattern to channel the gap. The value of the water gap of 5mm in this work was achieved at 22KV. Figure 3 shows the streamer initiation and development between the two electrodes for the minimum breakdown voltage. The figure shows the initiation of the streamer at the head of the pin because of the highest values of the electric field. It is found that the initiation time is 0.5435μsec and the required time for the streamer growth to embankment the gap between the two electrodes and reach the plane is 3.04μsec. Also, the streamer path was traced by trend the center of the opposite electrode (Figure 3).

Electric potential and field distributions

Initially, the solution of Laplace's equation gives the voltage at every node on the gridand then we know the voltage distribution as well as the field distribution. Figure 4 & 5 show our simulation pictures of the voltage and electric field distributions development with time. Also, we observe corresponds to the growth streamer path in the previous item. These figures suggest obviously the locomotion of the region of the highest voltages and the highest electric field agrees to the streamer growth. The plots for the magnitude of the electric field can attain the weak region where the breakdown may begin. In this case, the weak region was identified to be the region where the magnitude of the electric field is the highest and from this region the breakdown will initiate.

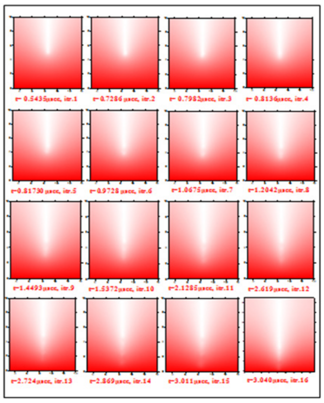

Figure 4: the voltage distribution with the time within pin - plane configuration in water with electrode gap of D=5 mm, and applied voltage of V=22 kV.

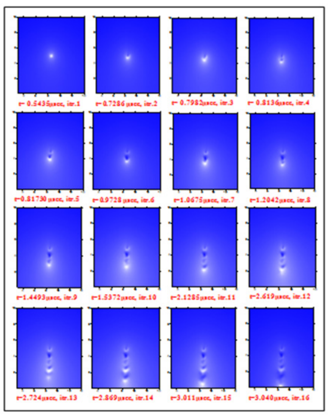

Figure 5: Magnitude distribution to the electric field distribution with the time within pin - plane configuration in water with electrode gap of D=5 mm, and applied voltage of V=22 kV.

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Streamer branching

The simulation was reiterated at the same mesh, but with different applied voltages (22, 25, 27, 30 and 33 KV). That is to clarification the effect of applied voltage on the streamer branching as in Figures 6. From the Figure 6 the one can notice that, the number of branches increases with the increasing of the applied voltage due to the increased number of elements inside mesh that is realized condition of the growth of streamers inside liquid. Also, the streamer growth with the shortest distance between the electrodes with the increase of the voltages on the anode (pin), which leads to a decrease ($\Delta\tau_{arr}$). This is consistent with studied many experiential and theoretical researches [26-28]. Table 1, shows the number of branches and arriving time at each applied voltage.

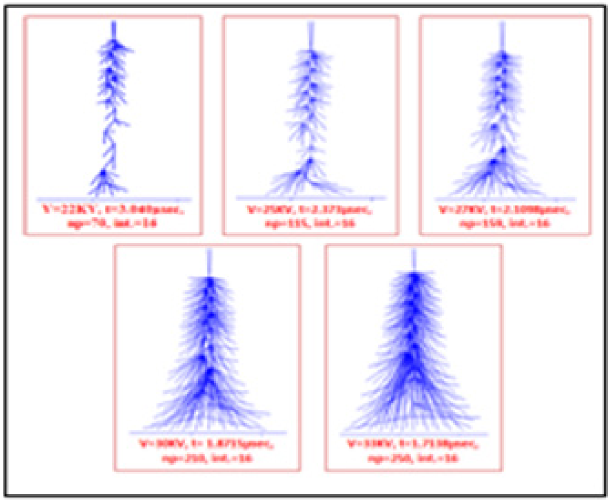

Figure 6: The propagation and branched structures of streamers (At each time step) for different applied voltage within pin - plane arrangement in water with electrode gap of D=5 mm.

Table 1: The arriving time and the number of branches at each applied voltage.

	Applied Voltage (kV)	Arriving Time(µsec)	No. of Branches
Dielectric Liquid (Water)	22	3.040	70
	25	2.373	115
	27	2.109	159
	30	1.871	210
	33	1.713	250

Conclusion

From the results that were acquired by the simulation, the following conclusions can be presented as below:

The use of the computer, based on bubble model, can give good results when compared with the experimental procedures.

The higher electric field value is at the shape edge, demonstrate the initiation of the streamer.

The number of branches and their positions depend on the applied voltage value.

The time ($\Delta\tau_{arr}$) required to arrive the plain pole decrease with the increasing of the applied voltage.

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