The Streamer Discharge Propagation Within Normal Hexane and Acetone Liquids

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Abstract

Based on the streamer growth model, the streamer discharge propagation was simulated in aid of finite element technique. That was done within two non- mixed dielectric liquids (Normal-Hexane and Acetone) located between two electrodes in pin - plane configuration. The output results show that, the path of the streamer was affected by the interface between the two liquids; the streamer path crosses this interface under some conditions such as the permittivity of the liquids and the distance between this interface and the tip of the pin. Under other conditions, the streamer path grows along the interface. The results were assisted by the development of the potential and the electric field distributions with the growth of the streamer propagation within the configuration.

Key words
Numerical simulation, streamer discharge, Dielectric liquids.

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انتشار تفريغ التدفق داخل سوائل الهكسين الاعتيادي والأسيتون

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الخلاصة

جرت محاكاة انتشار تدفق التفريغ باستخدام تقنية العناصر المحددة واستنادا إلى نموذج نمو التدفق داخل سائلين لايختلطان (الهكسين الاعتيادي والأسيتون) بين قطبين كهربائيين في ترتيب إبرة- مستوي. وقد بينت النتائج إن مسار التدفق تأثر بالحد الفاصل بين السائلين حيث يقطع مسار التدفق الحد الفاصل تحت شروط محددة للمساحية الكهربائية للسوائل والمسافة بين الحد الفاصل وراس الإبرة كما بينت النتائج إن مسار التدفق يكون على طول الحد الفاصل تحت شروط أخرى. هذا وقد دعمت النتائج ببيان تطور توزيعات الجهد والمجال الكهربائيين مع انتشار نمو التدفق داخل الترتيب.

Introduction

The breakdown processes in dielectric liquid is the connection of the two electrodes by conducting channel, the investigation of this conducting channel in dielectric liquid is the essential problem for the theoretical as well as the practical work in this field. A detail understanding of the breakdown mechanism can help in the design of electrical equipment and to prevent failures. Unfortunately, there is no single theory that can best explain the breakdown event in liquid. There are many theories and hypotheses in the field of theoretical study of breakdown, but each of them couldn’t answer all questions arise through the discussion of breakdown process. In general these hypotheses are distributed into three groups. The first is called the electronic theory; this theory started by Macfadyn

[1] in 1953and was continued up to 2000 [2]. The second theory is the suspended particle theory, Kok and Corbey [3] in 1957 have advanced a quantitative theory of breakdown due to solid particles and suspended colloidal matter in the liquid. Since this theory depends on existing the suspended particle. It can't be applied for purity liquid and consequently loses its generality for investigation, so this theory damped rapidly. The third is called the bubble or cavity theory, started by Watson [4] in 1960 and W.G. Chadband and G. T. Wright [5] in 1965. This theory advances up to now. There are another assumptions and hypotheses but all of them related in some way with above main three theories. Today with the developed of the new fast computers, it is possible to study the details behind the initiation and propagation of the events that lead to breakdown. An extensive studies were done with a computer simulation method [6-8]. This work is a computer simulation method to study the pre-breakdown events in non mixed dielectric liquids (Normal Hexane and Acetone) especially the case of liquid-liquid interface. That was done pin-plane electrodes configuration.

Modeling of the Problem

Many facts about the pre-breakdown mechanisms for dielectric liquids are still waiting for adequate theoretical explanation. The streamer growth model uses Garton and Krasuck's [9] approach of bubble discharge. This model based on some assumptions;

1- The streamer growth probability depends on the local strength of the electric field [8]. That needs Laplace's equation, in two dimensions, to be solved.

$$\frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial V}{\partial x}\right)+\frac{\partial}{\partial x}\left(\varepsilon_y \frac{\partial V}{\partial y}\right)=0 \quad \ldots\ldots(1)$$

ε_x and ε_y are same for isotropic material and

$$\varepsilon_x=\varepsilon_y=\varepsilon=\varepsilon_o\varepsilon_r \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Where ε_o is the free space permittivity and ε_r is the relative permittivity of the dielectric the electric field has two components E_x, and E_y are given as:

$$E_x=-\frac{\partial V}{\partial x},\quad E_y=-\frac{\partial V}{\partial y} \ldots\ldots\ldots\ldots\ldots(4)$$

2- A weakly ionized spherical gas bubble is suggested to form at the streamer tip, and the streamer channels are conductors have very high resistance [9]. The streamer resistance (R_s) can be calculated such as

$$R_s=\frac{2\sigma l_s\rho}{\pi p_b b^3\gamma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where σ is the surface tension, l_s is the streamer length, ρ is the plasma resistivity, p_b is the pressure within the bubble, the radius of the bubble, and γ is the ratio of the major to miner semi-axis of the bubble.

3- The first streamer branch starts from the tip of the pin and other streamer branches start from the region with the highest electric field and extend to surrounding regions. More details describe this model was given by [10].

The Simulation

To employ the streamer growth model, a simulation was done to follow the streamer within the pin-plane configuration filled by N-hexane and acetone liquids. A Fortran program was written to do this simulation. The program consists of main and 9 subroutines programs, figure (1).

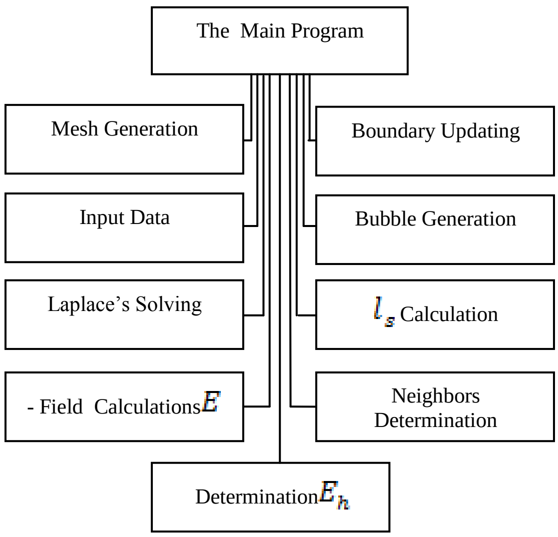

Fig. (1): The Block diagram of the simulation program.

The execution of the simulation requires that, main program calls the subroutines respectively.

1-Mesh generation: It generates the mesh as input data and insert the boundary (the known applied voltage values on both electrodes).

The region of interest for pin-plane Configuration is that which surrounds the pin tip. This is because a high electric field is expected in this region. Therefore, the elements in the grid are not made with the same size. This is important in saving the time in running the program of solution. The elements close to the pin tip are made very small and those faraway are larger, as shown in figure (2). A mesh (grid) is constructed that contains 4514 nodes and 8628 elements. We designed this grid contains many mesh areas with a special index for the elements of that area to handle the second liquid and spacing the interface between the two non mixed liquids from the pin.

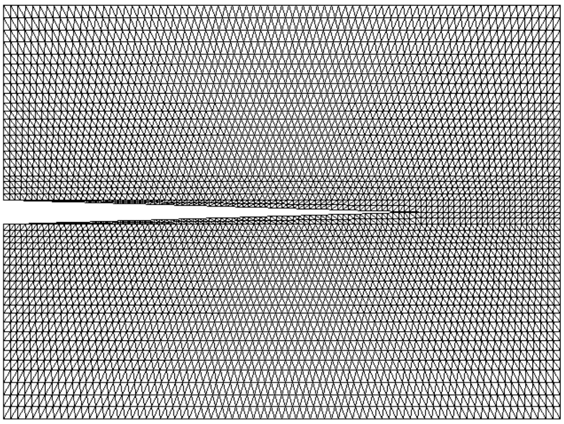

Fig. (2): The grid for the pin - plane configuration.

2-Input data: The required data for the simulation program must be inserted by this subroutine such as: the permittivity of the two liquids, the surface tension, the external applied pressure, the bubble radius, and some of well-known physical constants.

3-Laplace's solving: Simple2 package [11] has been used to solve Laplace's equation numerically in two dimensions. It prints the output of the solution as values of the voltage on nodes of the mesh.

4-E-Field calculation: In this subroutine, the program reads the voltage and coordinates of the nodes and calculates the electric for each element in the mesh.

5-E_h Determination: According to the values of the electric field for each element, which is calculated above, the highest value,E_h is selected.

6-Neighbour determination: The streamer can propagate anywhere in the dielectric but it is limited to one step for each branch. This one step of branch grew in the neighbor elements to the element of $E_h$value. So that, they must determined.

7-l_s Calculation: The streamer length for one step (iteration) is the distance between two following elements having the highest electric field values. The sum of lengths for all steps gives the final streamer length.

8-Bubble generation: A weakly ionized spherical gas is required to the streamer propagation; some calculations such as pressure within the bubble, concentration of neutral particles, and the electrons density. These parameters used to calculate the streamer resistance.

9-Boundary updating: The boundary conditions must be updating after each iteration (step) where the drop voltage across the streamer is subtracted from the streamer tip voltage.

The above items,3-9,must be repeated for each streamer step.

4. The results and Discussions

The simulation is employed for spacing distances between the pin tip and the liquid – liquid interface are 0.5mm, 1.0mm, 1.5mm, and 2.0mm.

4.1. (0.5) mm distance between the tip and the interface

Our simulation, for this distance, gives the results shown in figure (3). This figure shows the complete configuration for the streamer propagation within n-hexane and Acetone liquids.

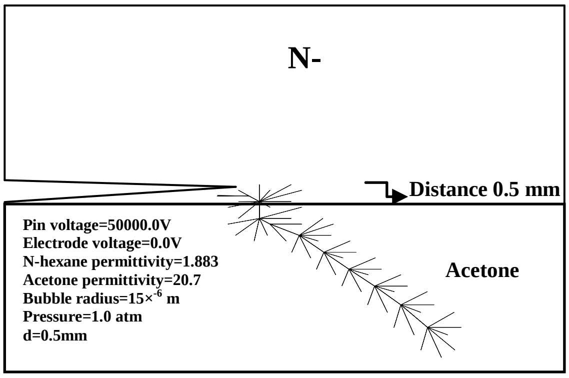

Fig. (3): The effect of the liquid-liquid interface (n-hexane with Acetone) on the streamer growth path, the complete configuration.

There is a clear deflection of the path of the streamer growth directly towards the second liquid cross the interface. That is because of the high permittivity of the Acetone. Now, we will prove the above result by the development of the voltage an electric filed distributions according to the streamer growth within the configuration.

Figures (4) and (5) show contour plots for the voltage and electric field distributions within the configuration.

Figure (4) shows the enlargement of the region between the two electrodes. It is clear that, one can observe the effect of the streamer growth on the voltage distribution within this region. It is clear the deflection of the streamer according to the development of the distribution.

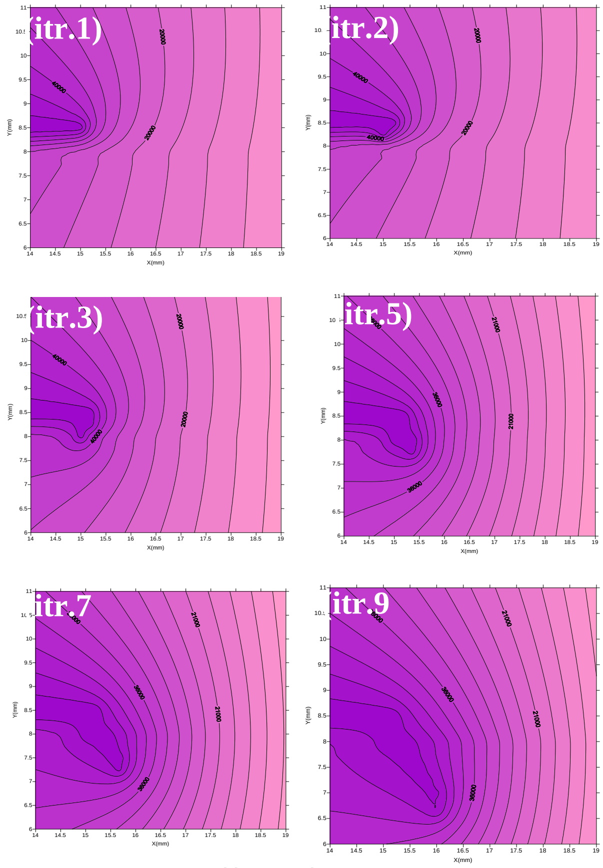

Fig. (4): The effect of streamer growth on the voltage distribution for iterations 1, 2, 3,5,7,9 in n-hexane with Acetone.

According to the model which is the base of this work, the region of the highest electric field value is the site of the streamer discharge initiation and growth. In figure (5), we can clearly see the movement of the region with the highest value (bold region) according to the streamer growth between the electrodes.

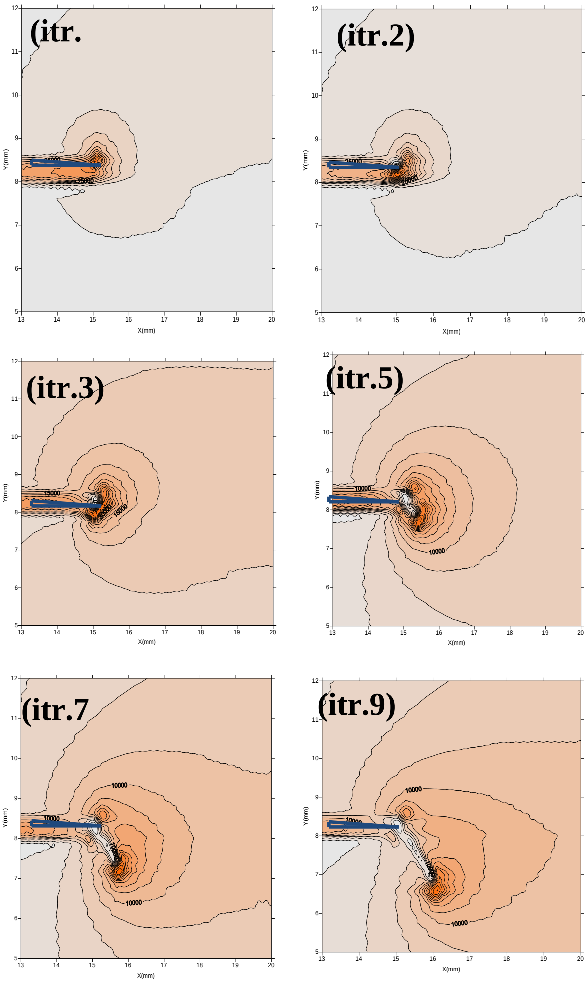

Fig. (5): The effect of streamer growth on the electric field distribution for iterations 1, 2, 3,5,7,9 in n-hexane with Acetone.

4.2. (1.0 mm) distance between the tip and the interface

To show the effect in this case (distance effect), figure (6) shows the complete configuration for the streamer growth which is near the interface within second liquid. Also here, can show a different deflection of the path of the streamer growth. In this case the deflection is less than that in the previous case. This is because of the interface and the second dielectric liquids.

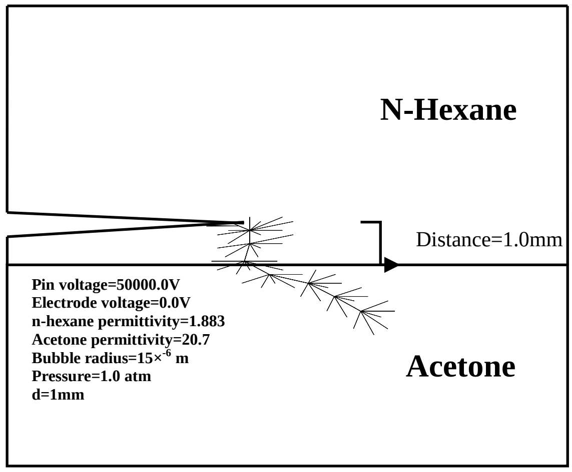

Fig. (6): The effect of the two dielectric liquids interface on the streamer growth path for the case of 1.0mm distance.

4.3. (1.5 mm) distance between the tip and the interface

In this part the distance between the liquid-liquid interface and the tip of the pin (needle) is 1.5mm. The effect of this distance on the streamer growth, is shown in Figure (7).

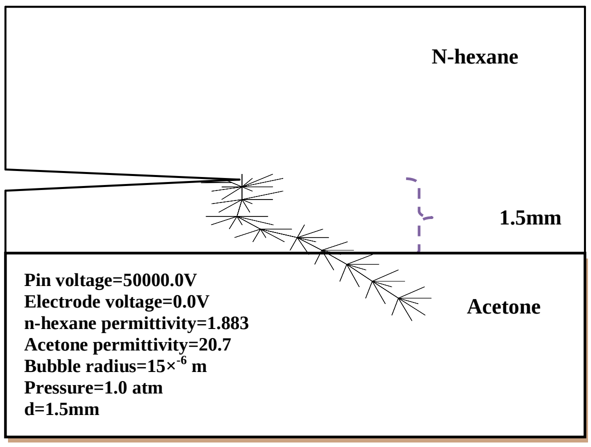

Fig. (7): The effect of the two dielectric liquids interface on the streamer growth path for the case of 1.5mm distance.

It shows the complete configuration with the streamer for this case. The figure appears that, the streamer growth not directly towards the interface. From this figure, we can see the deflection of the path of the streamer growth, because of the distance effect between the tip of pin to the two liquids interface, the streamer growth toward the plane electrode with some deflection.

4.4. (2.0 mm) distance between the tip and the interface

Here the distance between the interface of the two dielectric liquids and the tip of the pin (needle) is 2mm, using the same grid, and the same design except the distance. The distance effect is tested within same liquids n-hexane and Acetone, to show the streamer propagation and its path. Figure (8) shows the complete configuration with the streamer. Here, it appears clearly, there is no deflection of the path of the streamer growth, it shows no effect to the interface, because it becomes far away from the tip of the pin.

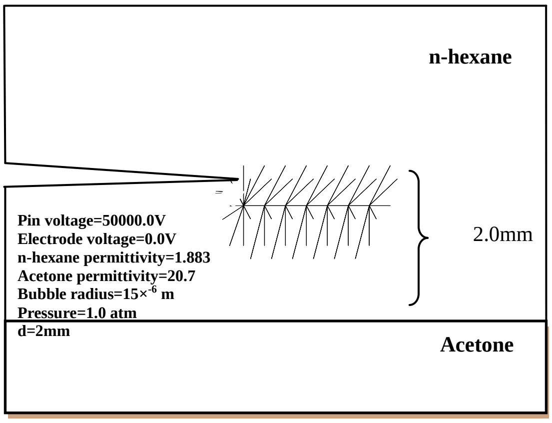

Fig.(8): The effect of the two dielectric liquids interface on the streamer growth path for the case of 2.0mm distance.

5. Conclusions

From an overall observation to the results of the present work, one can summarize some conclusions as:

1-The higher electric field value is at the shape edge, explains the initiation of the streamer.

2-In most cases, the presence of liquid-liquid interface, creation of weak regions (region with high value of electric field), which become suitable path to the streamer growth.

3-The liquid-liquid interface with its distance from the tip of the pin controls the path of streamer growth.

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