UNIVERSITY OF Southampton
School of Electronics and Computer Science


# Modelling the Streamer Process in Liquid Dielectrics

**Chilong Jiang, Paul Lewin, Wenxia Sima**
University of Southampton, Southampton, UK

## Introduction

For many applications, liquid dielectrics are superior to solid or gaseous electrical insulation materials. Advantages of liquids include higher breakdown strength compared to compressed gases. When compared with solid dielectrics, their ability to circulate leads to better thermal management and easier removal of debris after breakdown. Liquid dielectrics are also better suited to applications involving complex geometries. Thus the electrical behaviour of dielectric liquids subjected to high electric fields has been intensively studied.

Electrical breakdown of dielectric liquids is a very complex process that involves a succession of inter-correlated phenomena (electronic, mechanical, thermal, etc.). Moreover, experiments have shown that characteristic features of prebreakdown and breakdown phenomena greatly depend on experimental conditions (electrode geometry, shape and duration of applied voltage, liquid nature and purity, etc.). Rather than attempt to treat all phenomena associated with breakdown, it has been decided for the sake of clarity and brevity to restrict discussion to modelling the streamer processes occurring in mineral transformer oil.

## Model Description

Electrical prebreakdown in transformer oil is characterized with formation of streamers. These structures form when the liquid is highly stressed. Under a high electric field stress, the liquid molecules are partly ionized into free charge carriers, which move with velocities according to the field strength and their mobilities. However the density of commercial transformer oil inevitably varies in the bulk of the whole gap. Some local regions are low density as a result of density vibration or evaporation due to Joule heating caused by the movement of charge carriers. Within these local regions, the streamer develops in a gaseous phase. In our model, we first judge whether the region is of low density, then a streamer development mechanism in either the gas phase or the liquid phase is applied as appropriate. Once the streamer bridges both electrodes, the simulation is halted. The whole process is shown in the flow chart below.

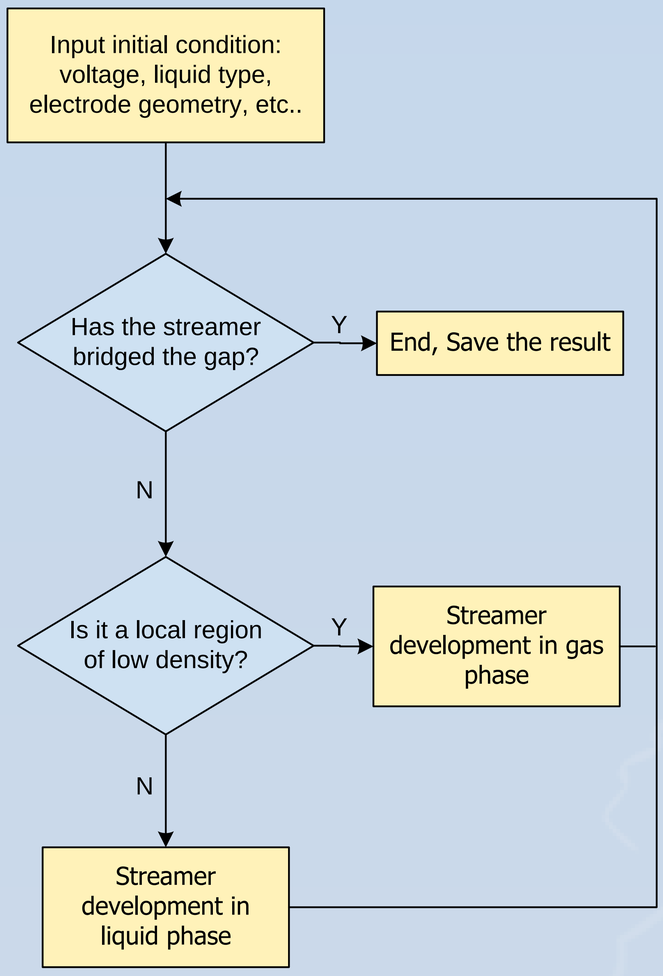


Fig. 1 The calculation process

## Electro-hydrodynamic Equations

The fundamental equations of streamer development include Poisson's equation and the charge continuity equations of positive charges, negative charges, and electrons. In this simplified model the diffusion of charge is neglected.

$$\nabla\bullet(\varepsilon_r\varepsilon_0\vec{E}) = \rho_p + \rho_e + \rho_n \tag{1}$$

$$\frac{\partial\rho_p}{\partial t} + \nabla\bullet(\rho_p\mu_p\vec{E}) = G(\vec{E}) + \frac{\rho_p\rho_e R_{pe}}{q} + \frac{\rho_p\rho_n R_{pn}}{q} \tag{2}$$

$$\frac{\partial\rho_n}{\partial t} - \nabla\bullet(\rho_n\mu_n\vec{E}) = -\frac{\rho_p\rho_n R_{pn}}{q} \tag{3}$$

$$\frac{\partial\rho_e}{\partial t} - \nabla\bullet(\rho_e\mu_e\vec{E}) = -G(\vec{E}) - \frac{\rho_p\rho_e R_{pe}}{q} \tag{4}$$

The subscripts '*p*', '*n*', and '*e*' represent positive charges, negative charges, and electrons respectively.

The *G* term represents the generation of charge carriers in either the liquid phase or the gas phase according to the local region density. In the liquid phase, the molecular ionization charge density rate is based on the Zener's theory. In the gas phase, charge generation is based on Townsend's theory.

$$G_{liquid} = e^2 n_0 \alpha\left|\vec{E}\right| \exp(-\pi m\alpha U^2/eh^2\left|\vec{E}\right|)/h \tag{5}$$

$$G_{gas} = \alpha_{Townsend}\rho_e\mu_{e(gas)}\left|\vec{E}\right| \tag{6}$$

The e, $n_0$, $\alpha$, $U$, $m$, $h$ and $\alpha_{Townsend}$ represent the electronic charge, the number density of ionizable molecules, the molecular separation, the molecular ionization potential, Planck's constant, and Townsend constant respectively.

The *R* term represents the recombination rate between heterocharged carriers.

## Simulation Geometry

The simulation geometry consists of a needle electrode and plane electrode. The needle tip radius is 50μm, and is 2mm away from the plane electrode. The relative permittivity of the oil gap is 2.2. The whole domain is divided into 4 subdomains. The closer to the symmetric axis, the finer the mesh of the domain.

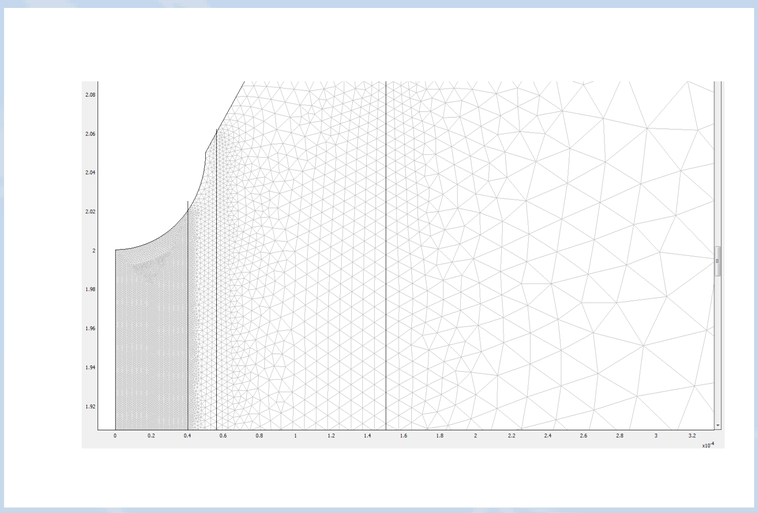

Fig. 2 Illustration of meshing used in the simulation

## Simulation Results & Future Work

A 10kV/100ns negative impulse voltage is applied to the needle electrode in the simulation. The electron concentration C2, space charge density, electric field distribution and potential distribution along the symmetric axis at time 10ns, 50ns and 100ns are shown in Figure 3.

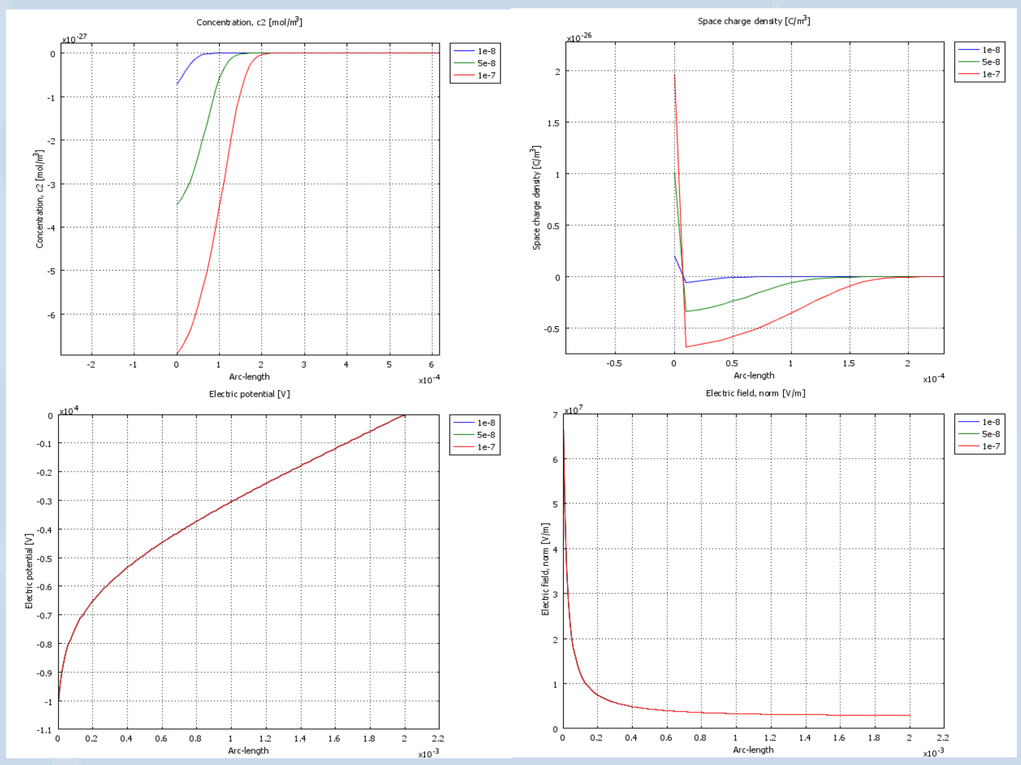


Fig. 3 The electron concentration, space charge density, electric field and potential distribution along the symmetric axis at time 10ns, 50ns and 100ns

From this result it can be concluded that electron concentration is increasing with time and electrons are moving from the negative electrode to the grounded electrode with considerable velocity. Within the time scale of interest, the positive and negative charge carriers can be seen as stationary. As the generation rate is much larger than the recombination rate, there are more positive charges than negative charges, and the space charge density near the negative electrode is positive. However, the space charge density is not high enough to distort the original field distribution. Thus the electric field and potential distribution are not characterized with significant change. In our future work, higher applied fields will be applied, in order to determine the effect of local space charge density on streamer development.

Contact details : cj8g11@ecs.soton.ac.uk
University of Southampton, Highfield, Southampton, SO17 1BJ, UK