

CALCULATION OF THE BREAKDOWN VOLTAGE IN AN ELECTRICAL DISCHARGE AT HIGH PRESSURE

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ABSTRACT: The subject of this work is the study of voltage in a discharge plasma at high pressure. The voltage is a very important parameter for industrial applications, found in the excimer lamps, plasma panels, and streamer even discharge crown. This breakdown describes the transition from state insulating gas to a state driver. We calculate the Paschen curve with an analytical resolution of the equation of self-sustained, and a fluid model 2D, which is based on the numerical solution of the two Boltzmann equations (equation of continuity and momentum), coupled to Poisson's equation, which represents the voltage depending on the product gap spacing-pressure product for various rare gases neon, argon and krypton, xenon.

KEYWORDS: electrical discharge, breakdown voltage, Paschen curve, analytical model, fluid model

1. Introduction

Plasma breakdown is the process that occurs when an electrically neutral gas absorbs enough energy for it to become ionized and electrically conducting. In laboratory plasmas, this is usually achieved by placing a large voltage across two electrodes: the applied electric field accelerates stray charges and begins the breakdown process [1]. Plasma breakdown, also referred to as plasma ignition, is an important fundamental process in plasma science and has a long history of study. It started in the late 19th century, Paschen [2] was the first scientist to study the electric breakdown of dielectric gases between metallic electrodes, and then formulate the so-called Paschen law which has been so effective in the prediction of electrical breakdown of dielectric gasses. Recently, Xiong et al [3] reported that two major contributing factors, namely roughness [4] and the ionization process of dielectrics, have dominant effects on the apparent electric breakdown of dielectric gases in the meso-and micro-scale [5]. In recent years, it has assumed new importance because many plasma applications are influenced by breakdown, and understanding of the breakdown process is necessary for further development of these devices. Such applications are diverse, including cleaning of exhaust gases [6], ignition of light sources [7, 8], and material processing using pulsed plasma sources [9, 10].

Breakdown theories appropriate for many situations have been developed [11], and the general features that characterize breakdown in different circumstances have become known. However, even for seemingly simple situations, some aspects are poorly understood.

There is a clear need for greater understanding of breakdown processes, but until recently the very short timescales associated with breakdown made direct experimental studies difficult. For this, several numerical and theoretical [12, 13] calculations are still underway to understand the breakdown mechanism

In the research described in this work was to gain a general overview of important features of electrical breakdown, and to understand how the discharge geometry and other parameters affect these processes. The simulation code used in this work is matrix AC-PDP (two-

dimensional) [14, 15]; Paschen curves dictate the breakdown voltage for a particular gas as a function of the p.d (pressure times electrode distance) product. This breakdown voltage curve represents a balance between the number of electrons lost by diffusion and drift in the inter-electrode gap and the number of secondary electrons generated at the cathode [16].

The fluid model and analytic model used in this study are described in section 2 and 3, respectively. In section 4 are discussed the results from the two models and followed by the discussion on the Paschen curve. Concluding remarks are presented in section 5.

2. Fluid model

The models must describe how the most realistic series of pulse discharges in reasonable computation times, and for two-dimensional geometries accomplished. It is very important to make a good compromise between accuracy and simplicity of the model. Depending on the degree of accuracy and speed desired. In this work a model was used, the fluid model in two dimensions field was divided into uniform cells in a Cartesian coordinate system based on solving the first two moments of the Boltzmann equation and the Poisson equation in a simple and direct. The method chosen is the following finite difference scheme of Ref [17], [18]. The two Boltzmann equations (equation of continuity and momentum) and Poisson's equation are represented by

$$\frac{\partial n_{e,p}}{\partial t} + \bar{\nabla} \cdot n_{e,p} \bar{v}_{e,p} = S_{e,p} \quad (1)$$

$$n_{e,p} \bar{v}_{e,p} = an_{e,p} \mu_{e,p} E - \bar{\nabla} \cdot (D_{e,p} n_{e,p}) \quad (2)$$

$$\bar{\nabla} \cdot \epsilon_r E = \frac{e}{\epsilon_0} (np - ne) \quad (3)$$

Where n is the density of charged particles (e for electrons, p for positive ions or negative). S is the source term of the equation of continuity, he reports the creation (ionization) and losses (attachments, recombination) of charged particles, $\bar{v}_{e,p}$ represents the average speed, E the electric field, $\mu_{e,p}$ is always positive corresponds to the mobility of electrons and ions, $D_{e,p}$ is the diffusion coefficient, ϵ_r and ϵ_0 are the dielectric and vacuum permittivity respectively.

To obtain the breakdown voltage, the fluid model 2D solves the electron and ion transport equations coupled with Poisson's equation (as in the simulation of voltage pulses). Breakdown is said to occur when the maximum total ion density reaches a given value within a given time interval, the result will obviously depend on the initial electron and ion density (supposed to be uniform in the gap).

In this work, we will review the various results obtained by the two-dimensional model, for a matrix plasma display panel cell. The design criteria are as follows (fig1). The dielectric covering the electrodes has a relative permittivity of 10. These electrodes are separated by a distance of 0.05 cm. This space is filled by various mixtures of rare gases (see fig.1).

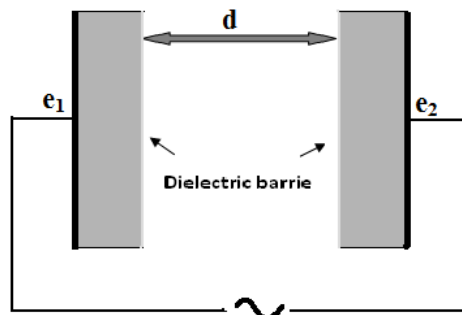


Fig.1: The geometry of the matrix cell.

3. Analytical Model:

Paschen described how the breakdown voltage changes with the pressure gas p , and spacing between electrodes d . It applies only to the electrodes of uniform field or the maximum field E exists in inter-electrode space. This breakdown voltage curve represents a balance between the number of electrons lost by diffusion and drift in the inter-electrode gap and the number of secondary electrons generated at the cathode [19]. Over a large range of pressures and electrode separations, the probability of ionization per electron-neutral collision in the gas and the probability of the production of secondary electrons by ion bombardment of the cathode are proportional to reduced field [20] and lead to the well-established pd similarity law. Indeed, the Paschen law, which represents the breakdown voltage of a gas in homogeneous field leaving obviously the self-sustained condition [21]. Breakdown involves the multiplication of electrons in avalanches. It should be noted that the existence of breakdown voltage depends on a critical number of electron multiplications throughout the ionization process induced by collisions between electrons and gas molecules. According to Nasser's book [22]. As such, the so called multiplication factor M (equation (4)) is a parameter that represents the number of electrons arriving at the anode if a secondary electron is emitted with cathode, it can be used to characterise breakdown. And of the expression of the first Townsend coefficient indicated by equation (5) [23,24].

$$M = \exp(\alpha d) = 1 + \frac{1}{\gamma} \quad (4)$$

$$\frac{\alpha}{p} = D_1 \exp\left[-D_2 \left(\frac{p}{E}\right)^{0.5}\right] \quad (5)$$

In general, α depend also only on the electric field at this point and can be deduced by experimental measurements from Huxley and Crompton [25] or by numerical calculations from Pitchford and Ségur [26,27]

Since α is the number of ionizing collisions per unit length, E is electric field, D_1 and D_2 they are positive constants, dependent on the composition of gas, the first Townsend ionization coefficient for the analytical model of noble gases, given in (4) [28,29].

To have a comparison enters the various analytical results, one could calculate the breakdown voltage, by the relation of the electronic multiplication M , according to the coefficient of ionization represented in equation (4) [30].

In plane geometry, where the breakdown voltage V_b is given by equation (6) [31-32], Where d is the electrode separation, M is electronic multiplication, p is the gas pressure. This equation represents the general formula of the breakdown voltage of pure gases.

$$V_b = \left| \left[\frac{pdD_2^2}{\left(\ln\left(\frac{M}{D_1pd}\right)\right)^2} \right] \right| \quad (6)$$

4. Results and discussion:

Our stated goal in this paper is to compare the different Paschen curves for xenon, neon, argon and krypton that are obtained by measuring the breakdown voltage of gas within a fluid model with two electrodes, in matrix geometry, As well as the analytical model describe by the resolution of the formula self-sustaining represented in equation (6), we used the electronic multiplication factor M which varies from 10 to 10^4 , for various gases Xe, Ne, Ar, and Kr.

In Fig. 2 we have shown simulation results for the breakdown voltage. Calculations were carried out at the gap size of 0.05cm and pressure was varied from 20 to 200 torr. And using two calculation methods, the analytical method solved by equation (6) and the numerical method describes by the fluid model. The general shape of these curves agrees with that obtained for experiment results [33]. The xenon plasma exhibits a maximum breakdown voltage at a pd of about 10 Torr.cm. That to mean the breakdown voltage increases in parallel with the increase of the product pressure-distance.

We observe a good agreement between the numerical results and the experiment results as well as the results of the theory from two values of electronic multiplication 10^3 and 10^4 .

The results displayed in fig.3 (presented by line) have been obtained with a 2D fluid model of the discharge Matrix cell shown in fig.1, the breakdown was said to have occurred when the initial density in the cell equal to $5 \cdot 10^6$ [35] (for this value of the density, the plasma had not yet formed but the distortion of the geometric field due to the ion space charge was large enough to always lead to a further increase of the current).

We see on fig.3 that the breakdown voltage increases considerably when the pd is increased there is insulation by the high pressure and the mean free path is weak. Our neon results agree with the analytic model counterpart. However, the minimum value for neon could be absolutely at 150 Volt for product (pd) of 2 torr.cm. Nevertheless, it should be pointed out that the Paschen curves obtained have the same pace with adjustments of increase and reduction in the breakdown voltage.

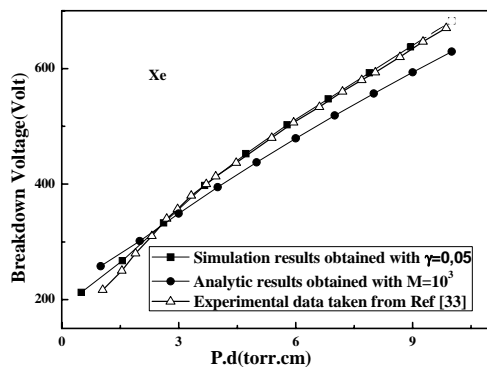


Fig.2: Breakdown voltage in xenon as a function of the gap spacing at the pressure. Results of calculations are given by solid symbols while the results of measurements taken from Ref [33], are shown by open symbols.

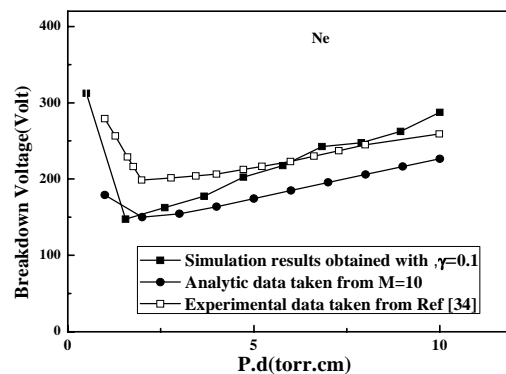


Fig.3: Dependence of the breakdown voltage on the pressure-gap spacing product in neon. Solid symbols correspond to the simulation results and the analytic results, who are obtained by the resolution of the self-sustained equation and open symbols correspond to the results of measurements experimental [34].

The fig.4, shows the simulate Paschen curves for argon for the gap between the electrodes of 0.05cm. The simulation results obtained by using 2D code and analytic model with the electronic multiplication (solid symbols) are compared with the experimental data (open symbols) taken from [33,34]. As seen in Fig. 4, the Paschen breakdown curves for argon obtained using the fluid model 2D coincide with the experiment results ref [33]ones, within the product p.d equal to 2 torr.cm accuracy, when the simulation accounts only for Ar ions. In all cases a good agreement between the experimental data and simulation results achieved taking into account the energy dependence of the secondary electron yield can be observed.

In figures 5 illustrate the plots of simulation and analytical data of Paschen curves for comparisons with experimental data [34], for krypton. The simulation results were obtained

including the emission effect and show relatively good agreement with the available experimental results. Differences that can be observed between simulation and experimental results could be explained by the fact that except slightly different operating conditions between the experiment and the simulation. And the other experimental conditions as the gap sizes, such as electrode material. Since the breakdown voltage strongly depends on the electrode surface conditions the onset of them can cause disagreement between simulation and experimental results. The model results overlap with the results of the theory for weak products p.d, and for high products the breakdown voltage in simulation becomes very large because of losses of electron by diffusion and absorption of cathode.

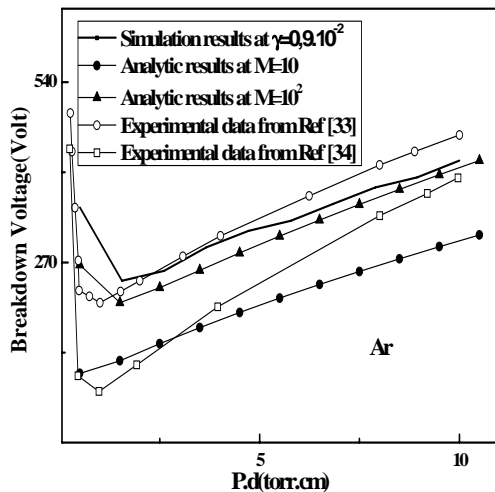


Fig.4: Comparison of the breakdown voltage according to the product p.d, between the analytical model and the fluid model and measurements of the experiment Ref [33,34], respectively.

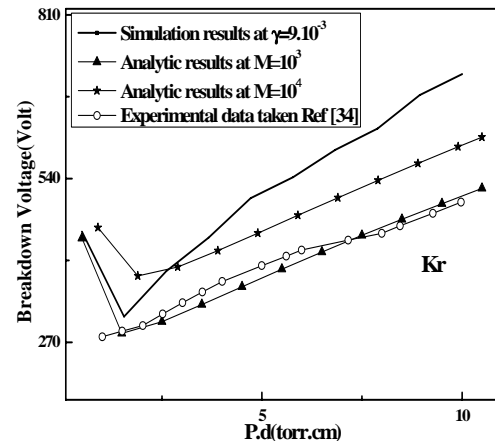


Fig.5: Breakdown voltage measurements as a function of pressure and gap spacing in pure krypton. The solid symbols represent the analytical calculation, and the numerical results indicate by line, or the secondary emission coefficient is set to 0.1, whereas the open symbol indicates experimental results [34].

5. Conclusion

To obtain a better understanding of the processes fundamental to dielectric gas-breakdown model has been developed to describe the breakdown phenomena in this paper. These "tools" will be used to obtain a better understanding of gas breakdown. Two basically different models are possible: a description by means of analytical resolution the self-sustaining equation, have using the electronic multiplication factor M which varies from 10 to 10^4 , that it depends on the gas nature, or a description by means of a model based on continuity and momentum equations coupled with the Poisson's equation of fluid model, in matrix geometry, near to the analytical geometry plan-plan.

We conclude that the breakdown process is controlled by the development of multiple electron avalanches. That meant that it depends on the parameters of discharge such as the gas nature and the geometry of the cell, and well on the product pressure-distance inter-electrode. It is interesting to note that the experimental results have good agreement with our simulation results and analytics in all pure gases.

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