EFFECT OF VARYING PRESSURE ON THE STREAMER PROPAGATION

N. Benaired[1] , A. Hennad[2]

1. Centre universitaire Ahmed Zabana Relizane
2. Université des Sciences et de la Technologie d'Oran Mohamed Boudiaf (USTO-MB, 31000 Oran (Algérie)

Abstract. In this paper, we have developed a multi-dimensional numerical code able to study the influence of many parameters as the pressure and the applied voltage in the propagation of streamer discharge. The transport equations system is solved by using Scharfetter and Gummel scheme coupling at time splitting method.

Keywords: 3D Fluid Model, streamer discharge, SG Scheme, Time Splitting Method

1. Nomenclature

Index e and p used for electron and positive ion respectively

n	Density
Φ	Charged species flux
S	Source term
V	Electric potential
E	Electric field
μ	Mobility of charged species
D	Diffusion coefficient of charged species
α	Ionisation coefficient
W	Drift velocity
P	Pressure
N	Density of the neutral gas
e	Elementary charge
ϵ_0	Permittivity of free space
Δx	Longitudinal spatial step
Δy	Transversal spatial step
Δz	Tangential spatial step
Δt	Temporal step

2. Introduction

The non-thermal discharges are usually used to produce plasmas usable for many industrial applications [1][2]. A considerable amount of numerical and experimental effort has been devoted to understand the dynamic of an electron avalanche and the streamers propagation [3].

The physicochemical properties of non-thermal discharges at atmospheric pressure are those of the micro-discharges. The developed numerical models simulate the propagation of the streamer by solving continuity equations of electrons coupled to the Poisson's equation to calculate the electric field.

The plasma ignition begins with an electronic avalanche. Electrons naturally present in the gas are accelerated by the applied external field. The electrons gain energy as they do not collide with a gas molecule. The average distance that an electron does not meet molecule depends on the pressure and gas.

Since it is in the ionized channel created during the ionization wave propagation and streamers that are created for the charged species of the plasma, it is clear that the improvement of this type of discharge requires a particular understanding of the formation and propagation of filamentary discharges.

The filamentary discharges can be applied to various pressures ranging from a few hundred to a few Pascal gaseous atmospheres. In addition, the filamentary discharges have the advantage of being easy produced in good conditions of stability and reproducibility [4][5].

The experiments those realized by Paschen to determine the influence of pressure on the characteristics of electrical discharges in gases, have enabled him to establish an empirical law on the behavior of gases, that is known as the Paschen law, and which states that the breakdown voltage of a gas between two parallel electrodes depends on the value of the product of the gas pressure with the inter-electrode distance.

The pressure and the applied voltage play an important role in the development of electric shock. The various studies show that the behavior of the discharge depends on many parameters such as pressure and applied voltage will strongly influence its characteristics. In this work, we have developed a multi-dimensional numerical code able to study the influence of the pressure in the streamer discharge propagation.

3. Hydrodynamic Model

We have adopted in this article the hydrodynamic model of order 1 to study the dynamics of charged particles during the formation of the streamer. This model consists of two first moments of the Boltzmann equation. For this, we assume the assumption of the local field and the neglect terms of higher density gradient to close the transport equations system. In the hydrodynamic model, the transport equations for charged particles are coupled to the Poisson's equation.

The equations we used are the same as those established by Dhali and Williams [6] [7]. The transport equations derived from first two moments of the Boltzmann's equation are written only for electrons and positive ions. These charged species constitute the active species in our electric discharge model.

The continuous equation describing the spatiotemporal variation of the charged species densities in this discharge take the form [3] [8] [9]:

$$\frac{\partial n\left(\vec{r},t\right)}{\partial t}+\frac{\partial \Phi\left(\vec{r},t\right)}{\partial \vec{r}}=S\left(\vec{r},t\right) \qquad (1)$$

With $\vec{r}\left(x,y,z\right)$ is the position vector

The sources terms $S\left(\vec{r},t\right)$ used by [6][7][10] are given by (2):

$$\begin{aligned} &S_e=S_p=\alpha\mu_e n_e E \\ &\alpha=5.7\ P\ exp\left(-260\ P/E\right) \end{aligned} \qquad (2)$$

The fluxes of the charged particles are given by:

$$\Phi\left(\vec{r},t\right)=n\left(\vec{r},t\right)W\left(\vec{r},t\right)-D\left(\vec{r},t\right).\frac{\partial n\left(\vec{r},t\right)}{\partial \vec{r}} \qquad (3)$$

The electric field and the potential in the electrical discharge are calculated using the Poisson's equation (4). $\rho\left(\vec{r},t\right)$ represents the net charge density.

$$\frac{\partial E}{\partial \vec{r}}=\frac{e}{\varepsilon_0}\rho(\vec{r},t) \qquad (4)$$

4. Numerical model and SG-time splitting method

The multidimensional resolution of the continuity equations for the particles charged is carried out by using the method of the time splitting [4][7][11]. In this method we replace the three-dimensional equation by a succession of the mono-dimensional equations in the object to reduce considerably the calculation time.

The equation (1) is given by the following successive expressions:

$$\frac{\partial n}{\partial t}+\frac{\partial \Phi}{\partial x}=0 \qquad (5)$$

$$\frac{\partial n}{\partial t}+\frac{\partial \Phi}{\partial y}=0 \qquad (6)$$

$$\frac{\partial n}{\partial t}+\frac{\partial \Phi}{\partial z}=0 \qquad (7)$$

$$\frac{\partial n}{\partial t}=S \qquad (8)$$

This method ensures the stability and allows for a fast convergence toward the searched solution, it also allows the simplicity of the programming with an important gain in the CPU time [12].

To solve the equations 5, 6 and 7 we use the Scharfetter and Gummel scheme SG0 that is presented by Kulikovsky [13]:

5. Results and Interpretations

The numerical resolution of the transport equations in our numerical model requires beforehand introduction of the boundary conditions and the initial conditions. In this paper, we have used the Neumann's conditions on symmetric axis for electronic, ionic densities, and for the electrical potential.

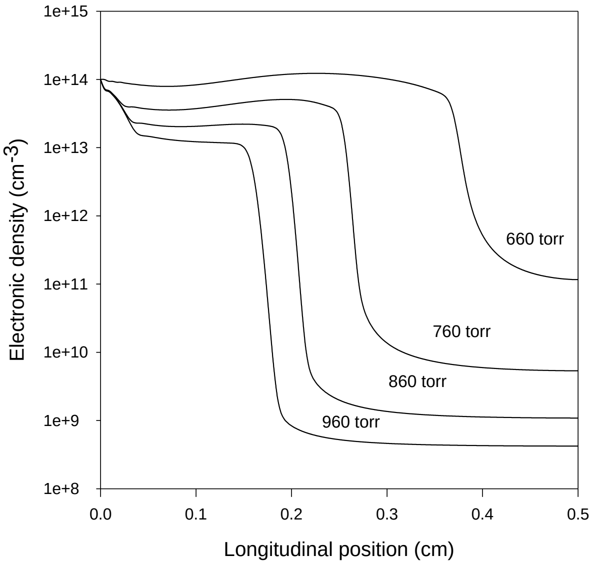

Figure. 1: Electronic density variations at 1.9 ns.

The three dimensional numerical model, that we described, makes possible to study the influence of the variation of certain physical parameters such as pressure on the negative streamer behavior. This numerical model was validated in the article of Benaired [12].

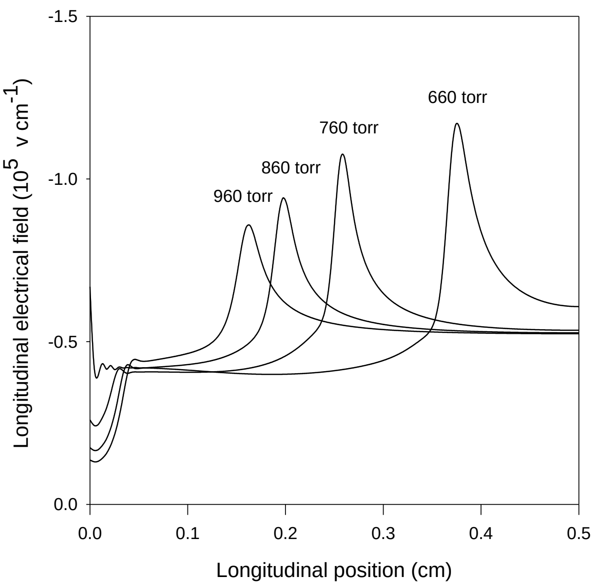

Figure. 2: Longitudinal electrical field variations at 1.9 ns

For that, we chose the discharge conditions similar to those of Dhali and Williams [6]: The pressure reference P of nitrogen gas is as 760 Torrs, the temperature is 300°K, the distance between electrodes is 0.5 cm and the reference applied voltage to the anode is 26 KV. Throughout this work, we use an initial Gaussian profile, placed on the symmetry axis

To study the pressure effects in the propagation of negative streamer, the pressure values are equal respectively to 660, 760, 860 and 960 Torrs which correspond to a pressure constant variation about 100 Torrs.

Figure 1 and Figure 2 show respectively the variation of the electronic density and longitudinal electrical field for various values of pressure at the time of 1.9 ns and an anode voltage of 26 kV. We note that the propagation of negative streamer is less rapid when the pressure of the medium increases. For example, the streamer propagation velocity increases 43% for 660 Torrs. It decreases 24% for a pressure of 860 Torrs and 37% for a pressure of 960 Torrs relative to atmospheric pressure of 760 Torrs.

We can explain this behavior by the physical fact that the mean free path and mobility of charged particles are inversely proportional to the gas pressure. That is to say that the probability of collision decreases with increasing pressure which causes a slowdown in the spread of the normal stream of negative cathode to the anode. The same behavior is observed on the evolution of the electric field. Note that the maximum electric field at the head of the streamer decreases with increasing pressure and that for physical reasons just mentioned.

6. Conclusion

In this paper, the multi-dimensional calculations of streamer propagation will provide a suitable test case for streamer models as they predict easily observable comportment. This resolution of the transport equations coupled with the Poisson's equation enabled us to study the dynamics of the particles charged in the case of a negative streamer with high pressure.

For a better comprehension of the evolution and the propagation of filamentary discharge in situations of strong variations of density and electric field the study of the effects of the pressure allowed us to see that the propagation velocity of the streamer is inversely proportional to the pressure increasing

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