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Numerical Modelling of Dynamic Nitrogen at Atmospheric Pressure in a Negative DC Corona Discharge

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1. Introduction

Plasmas are generated by supplying energy to a neutral gas causing the formation of charge carriers. Electrons and ions are produced in the gas phase when electrons or photons with sufficient energy collide with the neutral atoms and molecules in the feed gas (electron impact ionization or photoionization). The most widely used method for plasma generation utilizes the electrical breakdown of a neutral gas in the presence of an external electric field. Charge carriers accelerated in the electric field couple their energy into the plasma via collisions with other particles. Electrons retain most of their energy in elastic collisions with atoms and molecules because of their small mass and transfer their energy primarily in inelastic collisions. Discharges are classified as DC discharges, AC discharges, or pulsed discharges on the basis of the temporal behaviour of the sustaining electric field. The spatial and temporal characteristics of plasma depend to a large degree on the particular application for which the plasma will be used [1].

Today, plasmas are increasingly used in industry [1–3]. There are two types of plasma, the so-called thermal plasmas and cold plasmas said. The corona is a process that could lead to the creation of the latter. The use of techniques involving the corona tends to grow in importance. Indeed, they are out and already widely used in the areas of destruction of pollutants and waste gas, the surface treatment (cleaning and surface erosion, deposition of films, modifying the surface chemistry). They are also used in other applications such as ozone generation and elimination of static electricity. Also, to minimize development costs, recent research attempting to model the phenomena involved

In this work, we study the thermodynamics of the neutral gas subjected to energy injection as the result of electric discharge in the considered medium. This approach to the problem allows considering the discharge only on its energetic aspect. The discharge plays the role of an injection in the gas. To define the profile of this energy injection, we propose a mathematical function that represents the spatial dependence of the discharge density. The spatio-temporal evolution of the neutral gas particles is studied on the basis of hydrodynamic set of equations, i.e. equations of transport for mass, momentum and energy [4]. The hydrodynamic set of equations is solved by the F.C.T method (Flux Corrected Transport).

2. Description of corona discharge

Under the action of an electric field, the gas molecules undergo electron collisions, according to the complex mechanisms associated with shock [5]. The reactivity of the gas depends mainly on the shape of the energy delivered to the electrode system and generating the corona called "reactor ". Geometries are often very divergent and energy sources can be of multiple origins [6].

A corona discharge occurs when a current, power is created between two electrodes brought to a high potential and separated by an inert gas, usually air ionization plasma is created and the electric charges propagate through ions with neutral gas molecules. When the electric field at a point of a gas is sufficiently large, the gas ionizes around this point and becomes conductive. In particular, if one has been charged peaks, the electric field will be greater than elsewhere, this is usually as a corona discharge will occur, the phenomenon will tend to stabilize itself as the region becomes ionized conductive tip will apparently tend to disappear. The charged particles dissipate while under the influence of the electric force and neutralize an object in contact with opposite charge.

Corona discharges therefore generally occur between an electrode of small radius of curvature (for example: fault of the conductor forming a point) as the electric field surrounding area is large enough to allow the formation of a plasma. Corona discharge can be positive or negative depending on the polarity of the electrode with a small radius of curvature. If positive, it is called positive corona, otherwise negative crown [7]. Because of the difference in mass between electrons (negative) and ions (positive), the physics of these two types of corona is radically different.

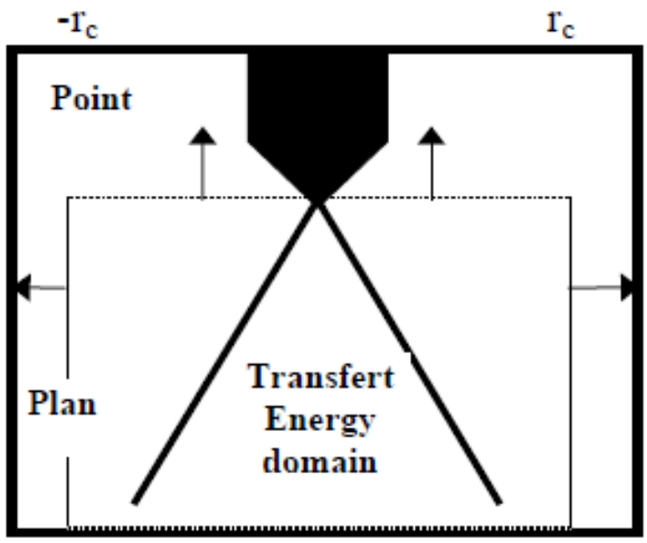

Fig. 1. domain study.

Landfills crown are guy characterized by asymmetry of the electrodes, at least one of the two electrodes with high curvature. Reduces the electric field produced in the electrode gap, when applying a high voltage is strongly inhomogeneous. The name of corona discharge is the luminous halo-shaped crown that appears around the electrode with high curvature at the initiation of the discharge. Deferent types of geometry are used in the experiments: tip-up, wire up, wire-wire and wire-cylinder. The high voltage applied to the electrode with high curvature can be positive or negative [8-9].

One of the main difficulties encountered with landfill type crown is the transition to the arc. This phenomenon is characterized by a strong rise in the current flowing in the discharge and a significant increase in the gas temperature. The plasma is then generated close to thermodynamic equilibrium [10].

In a point-to-plane configuration at atmospheric pressure, with the sharp electrode being supplied with a negative discharge DC [8], the corona discharge inception is principally due to the acceleration of background electrons (resulting from cosmic radiation) in the high electric field created by the small curvature radius of the point. The resulting space charge field, added to the 'geometrical' initial one, allows the electrons situated a little farther away to be accelerated [11].

The corona discharge is initiated when the electric field near the wire is sufficient to ionize the gaseous species. The minimum electric field is a function of the wire radius, the surface roughness of the wire, Nitrogene temperature, and pressure. The free electrons produced in the initial ionization process are accelerated away from the wire in the imposed electric field. More frequent inelastic collisions of electrons and neutral gas molecules occur [8].

Numerous models of corona discharge have been proposed. In [5] a wire-to-cylinder corona discharge is modelled by means of electronic injectors with azimuth symmetry, assimilating the coaxial discharge to a succession of elementary point-to-cylinder electrical discharges (Fig. 2).

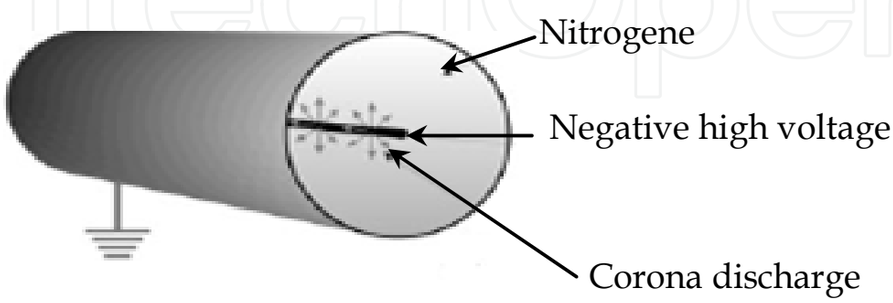

Fig. 2. Corona discharge in wire cylinder electrode geometry.

During the inception and development of the plasma in a point to plane gas discharge [10], a spatio-temporel evolution of the temperature of the neutral gas occurs as a result of plasma-neutral molecules energy interaction [11]. The temperature gradient causes a phenomenon of diffusion and convection as a result of the accompanied strong heterogeneity in the neutral gas density and pressure [12]. The fundamental role of neutral heating in the inception of gas breakdown has been shown by theoretical studies [13-14], as well as by experimental studies [15]. The behaviour of a point to plane discharge has been optically and electrically analysed for a centimeter gaps in Nitrogene at atmospheric pressure [16].

3. Introduction to kinetic theory

There are many phenomena in ionized gases for which we need to consider the velocity distribution function of the particles, or at least of some particles such as free electrons, and to use a treatment called kinetic theory. In fluid theory, the velocity distribution of each species is assumed to be Maxwellian everywhere and is therefore uniquely specified by the species temperature T. Because inelastic collisions, especially between electrons and neutral particles, play a major role in low-temperature plasmas, significant deviations from thermal equilibrium are usually present in such media, which justifies the need for using the kinetic theory. By definition, the velocity distribution function f(r, v, t) of a given species represents the number of particles of that species per unit volume of the six dimensional phase space at position (r, v) and time t. This means that the number of particles per unit volume in configuration space with velocity components between v_x and $v_x + dv_x$, v_y and $v_y + dv_y$, and v_z and $v_z + dv_z$ at time t is:

$$f(x,y,z,v_x,v_y,v_z).dv_x dv_y dv_z \tag{1}$$

When we consider velocity distributions, we therefore have seven independent scalar variables (r, v, t). The density in configuration space n = n(r, t), which is a function of only four scalar variables, is obtained by integration of f(r, v, t) over velocity space, that is

$$n(r,t) = \int_{-\infty}^{\infty} dv_x \int_{-\infty}^{\infty} dv_y \int_{-\infty}^{\infty} f(r,v,t)\, dv_z \tag{2}$$

The distribution function of simple speed allows us to calculate, for each position r and time t, the average value of certain physical properties, resulting in the so-called macroscopic or hydrodynamic quantities. Let A (r, v, t) a molecular property of any kind. The most general definition of its average value, denoted by A (r, t), is given by the expression:

$$A(\vec{r},t) = \frac{1}{n(\vec{r},t)} \int_{-\infty}^{\infty} A(\vec{r},\vec{v},t)\, f(\vec{r},\vec{v},t) dv^3 \tag{3}$$

3.1 The Boltzmann equation

The Boltzmann equation is derived rigorously from the Liouville theorem,. However, we can get this equation quickly, but in a formal way, by first assuming the absence of collisions between particles and, in a second time, taking into account the effect of collisions. The

Boltzmann equation is useful to describe the evolution of a gas of charged particles in an external electromagnetic field, and it obviously implies that the particles are small enough density does not change the outfield. It is written as follows [17]:

$$\frac{df}{dt} = \frac{\partial f}{\partial t} + \vec{v}.\vec{\nabla} f + \frac{\vec{F}}{m}.\vec{\nabla}_v f = \left(\frac{\partial f}{\partial t}\right)_{coll} \tag{4}$$

Here F is the force acting on the particles, and $(\partial f/\partial t)_{coll}$ is the time rate of change of f due to collisions. Considering, for example, free electrons, this collision term must account for elastic and inelastic electron–neutral collisions, and, at relatively high degrees of ionization, for electron–electron and electron–ion collisions. The symbol ∇ stands, as usual, for the gradient in configuration space (x,y,z) while the symbol ∂/∂v or ∇v stands for the gradient in velocity space.

Here, $\partial f/\partial t$ is the rate of change due to the explicit dependence on time. The next three terms are just v.∇f while the last three terms, taking into account Newton's third law m(dv/dt) = F are recognized as (F/m).($\partial f/\partial$v). The total derivative df/dt can be interpreted as the rate of change as seen in a frame moving with the particles in the six dimensional (r, v) space. The Boltzmann equation simply says that df/dt is zero unless there are collisions. Collisions have the effect of removing a particle from one element of velocity space and replacing it in another, or even creating a new particle in the case of ionization. One provides for this by the collision term $(\partial f/\partial t)_{coll}$.

3.2 The conservation equations

The conservation equations of density number, momentum and energy for a single species may be obtained by the method of moments. In this method, f (r, v, t) is multiplied with a function g(v) of the velocity and integrated over the entire velocity space. For the case that g(v) = 1, we obtain the continuity equation, if g(v) = m × v we obtain the momentum conservation equation, and if $g(v)= mv^2/2$, we obtain the energy conservation equation. The fluid equations are simply moments of the Boltzmann equation. The lowest moment is obtained just by integrating this equation over velocity space [17-19]:

$$\int_{-\infty}^{\infty} \frac{\partial f}{\partial t} d^3v + \int_{-\infty}^{\infty} \vec{v}\vec{\nabla} f \, d^3v + \int_{-\infty}^{\infty} \frac{\vec{F}}{m}\vec{\nabla}_v \, f \, d^3v = \int_{-\infty}^{\infty} \left(\frac{\partial f}{\partial t}\right)_{coll} d^3v \tag{5}$$

where dv stands for a three-dimensional volume element in velocity space. By transforming the third term on the left-hand side by Green's theorem and after straightforward calculations one obtains the continuity equation:

$$\frac{\partial n}{\partial t} + \vec{\nabla}(nu) = S \tag{6}$$

where u is the average (fluid) velocity:

$$u(\vec{r},t) = \frac{1}{n(\vec{r},t)} \int_{-\infty}^{\infty} \vec{v} \, f(\vec{r},\vec{v},t) dv^3 \tag{7}$$

S represents the net creation rate of particles per unit volume as a result of collisions (for example, in the case of electrons, this term takes into account new electrons created by ionization and electron losses due to recombination with ions or attachment).

The next moment of the Boltzmann equation is obtained by multiplying it by mv and integrating over dv. We have:

$$m\int_{-\infty}^{\infty}\vec{v}\frac{\partial f}{\partial t}\,d^3v + m\int_{-\infty}^{\infty}\vec{v}\,(v\vec{\nabla})f\,d^3v + m\int_{-\infty}^{\infty}\vec{v}(\vec{F}.\vec{\nabla}_v)f\,d^3v = \int_{-\infty}^{\infty}\left(\frac{\partial f}{\partial t}\right)_{coll}d^3v \tag{8}$$

After calculation we obtain [4]:

$$\frac{\partial nm\vec{u}}{\partial t} + \vec{\nabla}.(n\vec{u}\vec{u}) + \vec{\nabla}\Pi + \vec{\nabla}.p - n\vec{F} = \int_{-\infty}^{\infty} m\vec{v}\left(\frac{\partial f}{\partial t}\right)_{coll}d^3v \tag{9}$$

where Π denotes the viscosity, p denotes the pressure, and F the specific external forces exerted on the species. The first term of (9) represents the accumulation of the specific momentum, which is generally nonzero in a transient system. The second term denotes the momentum transport caused by the flow. The third term represents the viscous forces. The fourth term is the pressure gradient. Formany flowing systems, including the plasmas treated in this work, this is the driving force that causes the various plasma species to flow. The fifth term represents the external forces, thus the combined action of the electric force, the Lorentz force and gravity. Tight-hand side term represents the momentum gained and lost trough collisions with other species. This may include the transfer of momentum from other species, or the creation of species with nonzero momentum.

We have deduced the form of the equation of conservation of energy as a function of thermal energy, using the Fourier law for thermal conductivity and the ideal gas law [1,4]:

$$\frac{3}{2}\frac{\partial nk_BT}{\partial t} + \frac{3}{2}\vec{\nabla}(nk_BT\vec{u}) + p\vec{\nabla}.\vec{u} + (\vec{\nabla}.\vec{u})\Pi - \vec{\nabla}(\lambda\vec{\nabla}T) = \int_{-\infty}^{+\infty}E^T\left(\frac{\partial f}{\partial t}\right)_{coll}d^3v \tag{10}$$

with k_B Boltzmann's Constant, λ the thermal conductivity and E^T the thermal energy. By assuming the existence of a temperature T for the species, we implicitly assume Maxwell-Boltzmann equilibrium. However, (10) can readily be rewritten in terms of average particle energies if deviations from Maxwell-Boltzmann equilibrium are relevant.

The first term on the left-hand side of (10) denotes the accumulation of thermal energy, and generally is nonzero in the transient systems treated in this work. The second term represents the convective transport of energy by means of the systematic velocity of the species. The third term represents the expansion work. The fourth term is the production of thermal energy by viscous dissipation, which is in fact the transfer of directed kinetic energy to random thermal energy in the species. The fifth term represents the diffusive heat transport (thermal conduction).

The term on the right side represents the transfer of thermal energy by collision

4. Mathematical model

The discharge column is considered to be cylindrically symmetric and longitudinally uniform. It is quasi-neutral, weakly-ionized, and collision-dominated. The column is characterized by a current density distribution j(r,t), witch is a function of radius r as well as time t, and a longitudinal voltage gradient E, which is assumed independent of both position in the column and time. The current density j goes to zero at a fixed radius R_C. The ionized region, which is initially diffuse, is contained in an infinite background of perfect gas of particle density (at t=0) uniform at N_0 and T_0, respectively.

The rate at which thermal energy is added to the gas per unit volume is given by j(r,t) E(r,t). That is, all the input power is assumed to be transferred from the electron to the background gas. As the temperature increases, the gas expands and its density decreases near the axis. Where the gas density decreases the electrical conductivity and current density increase, thus enhancing the subsequent rate of heating and expansion [13].

The gas dynamics are described by the conservation equations for a viscous compressible fluid and the equation of state for a perfect gas. The equations are written in cylindrical coordinates, written rotational symmetry and axial uniformity, with gas flow in the radial direction only, and with zero body forces. The fluid equations are, for the conservation of masse (continuity equation).

$$\frac{\partial N}{\partial t}+\frac{1}{r}\frac{\partial (Nv_r r)}{\partial r}=0 \tag{11}$$

where N is particle density, r is function of radius as will as time t and v_r is the radial velocity.

For momentum (equation of motion):

$$MN\left[\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}\right]=-\frac{\partial p}{\partial r}+\frac{\partial}{\partial r}\left[\mu\left(2\frac{\partial v_r}{\partial r}-\frac{3}{2}\frac{1}{r}\frac{\partial v_r r}{\partial r}\right)\right]+\frac{2\mu}{r}\left(\frac{\partial v_r}{\partial r}-\frac{v_r}{r}\right) \tag{12}$$

where M is the masse of a gas molecule and μ is the coefficient of viscosity.

and energy, for a perfect gas,

$$\begin{aligned} &MN\left[C_v\frac{\partial T}{\partial t}+v_r C_v\frac{\partial T}{\partial r}+\frac{p}{M}\frac{\partial (1/N)}{\partial t}+\frac{p}{M}v_r\frac{\partial (1/N)}{\partial t}\right] \\ &=jE+\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda\frac{\partial T}{\partial r}\right)+\frac{4\mu}{3}\left[\left(\frac{v_r}{r}\right)^2+\left(\frac{\partial v_r}{\partial r}\right)^2-\frac{v_r}{r}\frac{\partial v_r}{\partial r}\right] \end{aligned} \tag{13}$$

where p is the gas pressure, C_v is the specific heat at constant volume, T temperature, λ is the coefficient of thermal conductivity.

The equation of state is:

$$p=Nk_BT \tag{14}$$

where k_B is Boltzmann constant

Energy transfer by radiation has been neglected. Eliminating the time derivative of N from the energy equation by using the continuity equation, replacing the pressure with Nk_BT, and rearranging terms, we can rewrite the conservation equations:

$$\frac{\partial N}{\partial t} = -\frac{1}{r}\frac{\partial (N v_r r)}{\partial r} \tag{15}$$

$$\frac{\partial v_r}{\partial t} = -v_r \frac{\partial v_r}{\partial r} - \frac{k}{MN}\frac{\partial (NT)}{\partial r} + \frac{1}{MN}\frac{\partial}{\partial r}\left[\mu\left(2\frac{\partial v_r}{\partial r} - \frac{2}{3}\frac{1}{r}\frac{\partial v_r r}{\partial r}\right)\right] + \frac{2\mu}{MNr}\left(\frac{\partial v_r}{\partial r} - \frac{v_r}{r}\right) \tag{16}$$

and

$$\begin{aligned}\frac{\partial T}{\partial t} &= -v_r \frac{\partial T}{\partial t} - \frac{kT}{MC_v N}\frac{1}{r}\frac{\partial (N v_r r)}{\partial r} + \frac{kT v_r}{MC_v N}\frac{\partial N}{\partial r} \\ &+ \frac{1}{MNC_v}\left\{ jE + \frac{1}{r}\frac{\partial}{\partial r}\left(\lambda \frac{\partial T}{\partial r}\right) + \frac{4\mu}{3}\left[\left(\frac{v_r}{r}\right)^2 + \left(\frac{\partial v_r}{\partial r}\right)^2 - \frac{v_r}{r}\frac{\partial v_r}{\partial r}\right]\right\}\end{aligned} \tag{17}$$

If viscosity and thermal conduction are neglected, the speed of sound in the gas v_s can be written:

$$v_s = \left(\frac{\gamma kT}{M}\right)^{1/2} \tag{18}$$

Where γ is the ratio C_p/C_v of the specific heat at constant pressure to that at constant volume [13].

5. Numerical analysis

The discharge studied in our work requires that the method used to solve the equations of transport is efficient and has the ability to follow the strong density gradients while keeping a reasonable computation time. To this end, we opted for the scheme of Flux Corrected Transport Low phase error has already been used successfully in several areas such as solving the Boltzmann equation in weakly ionized gases. The diagram FCT (Flux Corrected Transport) is certainly one of the best choices to make while it is quite complex. Among its advantages are: the absence of spurious oscillations, numerical diffusion minimum; It can also calculate the evolution of profiles with very sharp spatial variations [20].

Our work of the simulation of the discharge in space is two-dimensional with cylindrical symmetry. The hydrodynamic set of equations is solved by the F.C.T method (Flux Corrected Transport) using the procedure of time splitting for the two space variables. An FCT algorithm consists conceptually of two major stages, a transport or convective stage (Stage I) followed by an antidiffusive or corrective stage (Stage II) [20-22]. All transport

equations of the charged or the neutral particles defined previously obey the same generic form:

$$\frac{\partial}{\partial t}\varphi(r,z,t)+\frac{1}{r}\frac{\partial r\varphi(r,z,t)v_r}{\partial r}+\frac{\partial\varphi(r,z,t)v_z}{\partial z}=S(r,z,t) \tag{19}$$

where r, z are space variables, t is temporal variable, φ(r,z,t) is the transported size (density, momentum or energy) and S(r,z,t) indicates the source term of the corresponding transport equation.

The transport equations which are narrowly coupled are discretized by the method of volumes finished and are corrected by the method of the finished volume and corrected by the method of corrections of flow developed by Boris and Book [20].

The transport equations were discretized on the mesh nodes using numerical schemes to avoid the problems of digital broadcasting, which is especially important. To simplify the presentation of the method we consider a time step Δt constant, we divide the two-dimensional space into cells infinitely small. The application of this method involves three steps:

- The transport step: we calculate the value of the quantity transported and distributed in each node of the cell.
- The diffusion step to ensure that the solution is positive
- The next step is to reverse the spread where it is not necessary. Such an anti-diffusion step is necessary to find the accuracy of the transport step

The study domain is defined by figure 2. The limit velocity of the molecules on the surface is assumed equal to zero. As it is necessary to take into account the local heating effects, the temperature of the surface is assumed equal to the averaged temperature of the surrounding gas, and the temperature of the electrode body is assumed invariable and equal to the ambient temperature.

$$\frac{\partial N}{\partial r}(0,0,t)=\frac{\partial T}{\partial r}(0,0,t)=\frac{\partial v}{\partial r}(0,0,t)=0 \text{ and } T=293K,\quad v_r=0,\quad U=12\ kV \tag{20}$$

6. Results and discussion

In Figs. 3-6, the spatio-temporal evolution of temperature, density, pressure and speed of neutrals are shown, respectively, for the case of a negative point discharge, cold wall and constant injection of energy.

In Figure 3, we observe a growing neutral heating in the function of time. This transfer of heat is important for the discharge was near the center. Indeed ~ 10 mm (from the point), the temperature passes from the value 350 K at t = 1 μs to 650 K at t_6 = 50μs, whereas it remains almost constant near the edge and varies slowly near the cathode.

On the other hand the temperature increases rapidly with time, there is also a shift of the maximum temperature in the direction of the anode

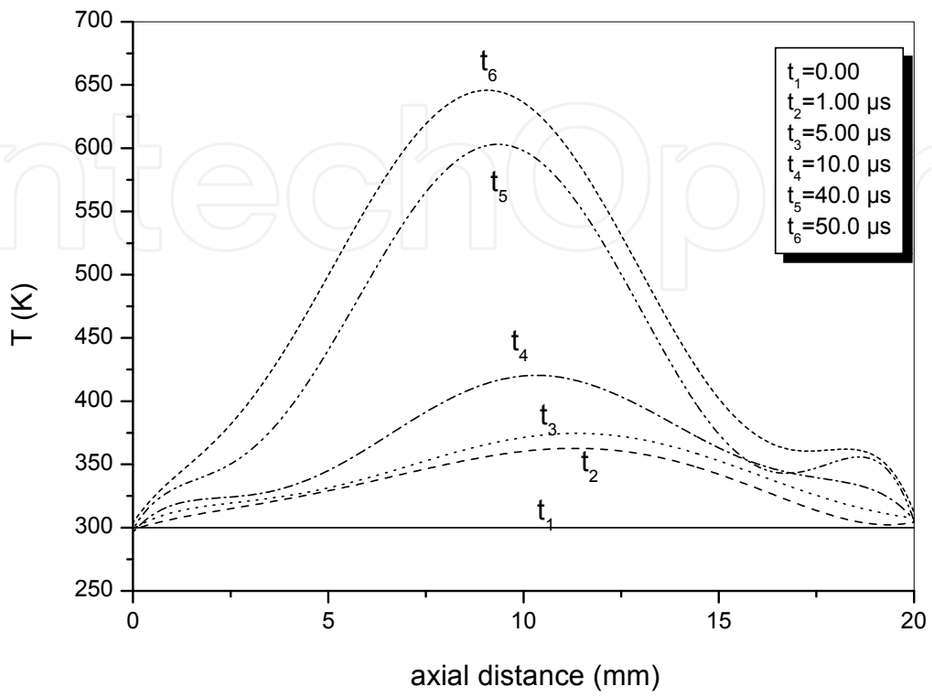

Fig. 3. The axial evolution of neutral temperature for several laps (negative point discharge, cold wall, constant injection of energy).

Figure 4 shows the evolution of the density of neutral in the function of time and space. We notice on all the curves a neutral depopulation in Inter electrode space. This decline results from the thermal footprint caused by the passage of the streamer discharge, it is more important at 10 mm (from the point), where there is a rate of 40% at t_6 = 50 µs , while there is a decline up to 5 % in t_2 =1µs. In the middle of the discharge are the ionization phenomena responsible for the decrease in the density of neutral or figures 5 and 6, which represents the evolution of the pressure and the module of the neutral speed, we notice, because of the inertia of molecules of gas, a phase shift between the maximum module speed and total maximum pressure. This gap is especially well marked on the axis, and at the beginning of the discharge. For other parts of the field, this phase shift is less accentuated because the disturbance created by the discharge is less important for intensity. As the time elapses, the evolution of pressure and speed module becomes constant.

From the moment 20 µs, we see a trend toward stationarity for all sizes (temperature, density, pressure and speed), because the heating in a comprehensive manner (contribution of all terms), decreases in intensity over time and the dissipation of energy becomes important. The result of all these processes, that all occurs as if a heating effect (known as heat wave) begins at the tip to spread towards the plan.

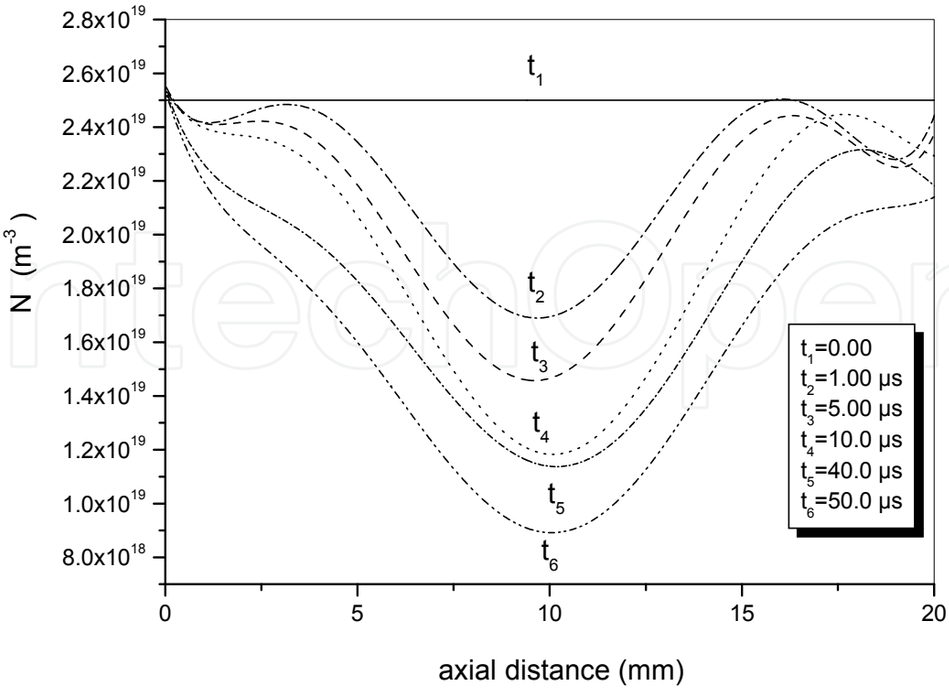

Fig. 4. The axial evolution of neutral density for several laps (negative point discharge, cold wall, constant injection of energy).

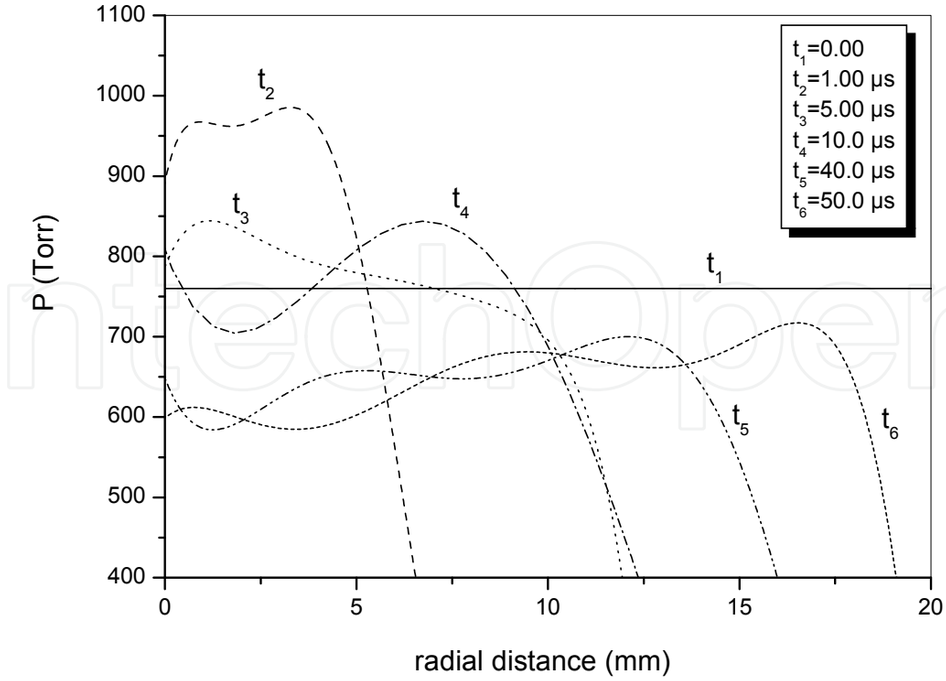

Fig. 5. The radial evolution of neutral pressure for several laps (negative point discharge, cold wall, constant injection of energy).

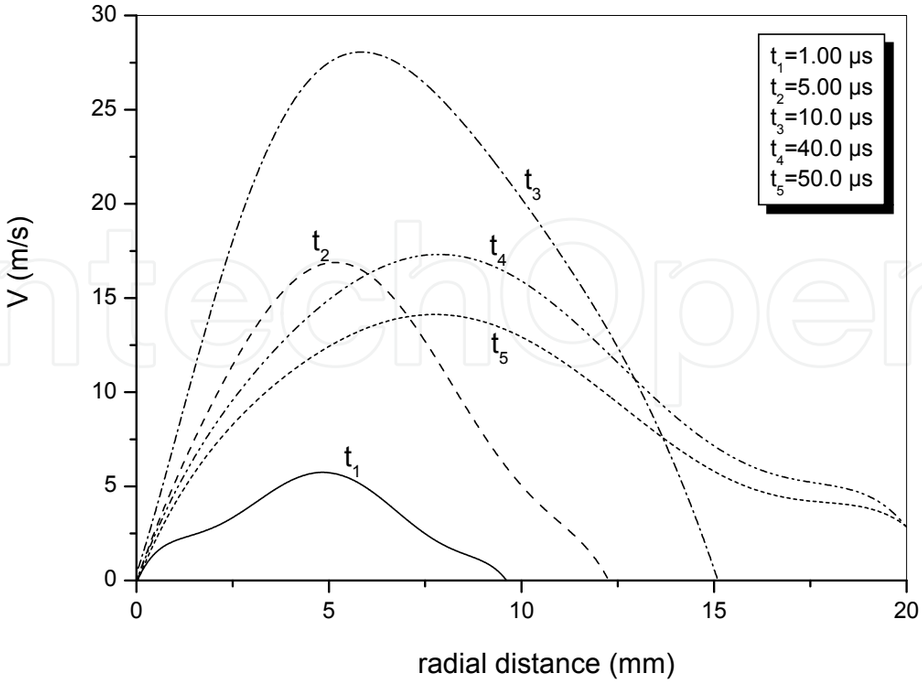

Fig. 6. The radial evolution of total speed module of neutral for several laps (negative peak discharge, cold wall constant injection of energy).

7. Conclusion

In this paper, we have presented numerical calculations for neutral thermal effects produced by the negative dc corona discharge DC at atmospheric pressure, is conducted.

The objective of this study is to develop an efficient numerical model for solving transport equations. This allowed us to study the evolution of temperature and density of neutral particles as a function of axial distance, in the case of a negative corona discharge at atmospheric pressure for a better understanding of the evolution and heat transfer in situations of large variations in density and electric field. We completed this approach by a numerical parametric study on the behavior of radial profiles of pressure and velocity neutral particles.

The results obtained reveal the existence of the phenomena of interaction between charged particles and neutral particles, which are causing instability reaction electric shocks. These instabilities can come from two sources:

- Electrostatic origin since the space charge occurring in the gas, change the local electric field.
- Thermal, since the energy transfer between gas ions and the neutral gas causes local variations in temperature and density of the neutrals.

The results show that the stabilization of the neutral gas is mainly on the function of the energy injection distribution, and depopulation is more important than the plane advance. So, as soon as a current goes through the neutral gas, obviously a Joule heating effect increases the temperature locally. These results also show that:

- Temperature increases with time, the middle of the discharge is warmer.
- The neutral density varies inversely as the temperature
- The appearance of a phase difference between the maximum speed of neutral and maximum total pressure module, due to the inertia of the gas molecules.

Due to its qualities of stability, accuracy and speed compared to digital technologies that preceded it, we can say that using the FCT method has opened new perspectives for modeling non-equilibrium discharges in general and in particular corona.

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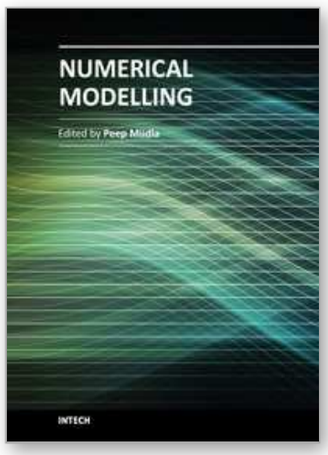

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This book demonstrates applications and case studies performed by experts for professionals and students in the field of technology, engineering, materials, decision making management and other industries in which mathematical modelling plays a role. Each chapter discusses an example and these are ranging from well-known standards to novelty applications. Models are developed and analysed in details, authors carefully consider the procedure for constructing a mathematical replacement of phenomenon under consideration. For most of the cases this leads to the partial differential equations, for the solution of which numerical methods are necessary to use. The term Model is mainly understood as an ensemble of equations which describe the variables and interrelations of a physical system or process. Developments in computer technology and related software have provided numerous tools of increasing power for specialists in mathematical modelling. One finds a variety of these used to obtain the numerical results of the book.

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