Modelling of Collision in the Plasma Sheath and the Cathode Erosion of Electrical Arc

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In order to improve many industrial applications of the plasma sheath and the cathode erosion of electrical arc, the prime objective of this paper is to treat the modelling and simulation of the effects of ions collisionality on the plasma sheath and to determine the collisional dependence of the sheath width and the ion impact energy on the wall using the Runge-Kutta Routrine on the presence or the absence of the term source in the continuity equation . Then , to explain the dependence of the measured erosion rate of the cathode by considering the cathode spot heat balance equation coupled with equation obtained from the sheath and taking into account the physical phenomena such as ion and electron fluxes, radiation, thermal conductivity and evaporation.

Keys Words : sheath, modelling collision, cathode erosion, impact energy, sheath width , spot

I-INTRODUCTION

When a plasma is in contact with a negatively biased surface, such as an electrode or wall, a strong , localized electric field appears between the plasma and that surface. This ion rich boundary layer, called the sheath, confines electrons in, and expels ions from, the plasma. The energy that ions gain as they fall through the sheath regulates both the physical and chemical processes that occur at surfaces contacting the plasma [1]. Such plasma-surface interaction is important, for example, in plasma processing. Ion collisions in the sheath can significantly reduce the ion impact energy on the surface, and so it is worthwhile to include them in a sheath model. Near the sheath region, elastic and inelastic collisions between ions and neutrals may play an important role on the sheath dynamics.

Sheath formation at the plasma-boundary interface, that separates the quasi-neutral plasma is ubiquitous in a bounded plasma. The governing physics of the boundary layer formation between the wall and the plasma have been studied for past many decades and are yet to be fully understood. The interest in the subject has been revived recently due to its wide ranging applications in plasma processing , in ion cyclotron heating , in electric propulsion devices , in fusion plasmas , in high speed air vehicles [2]. The electric propulsion devices, built up of sheath potential and its stability may severely affect the thrusters efficiency .

The interaction between the plasma and the limiter divertor, in a magnetically confined fusion plasma such as tokamak is important in the connection of plasma effect on the surface and the sputtering from the wall to the surface. Accurate sheath modelling is of considerable interest to the effective design of ionised flow. A unified theory of the cathodic spot in vacuum , proposed by Beilis [6], is the most complete from the microscopic point of view. For Beilis, the electrical arc root is composed of three superimposed zones following the normal direction of the cathode surface. The first zone is the electrode and its surface where we assume a steady state of energy transfer on the surface. The second zone is called the sheath zone, where the drop voltage accelerates the electrons emitted by the surface.

Emitted electrons and atoms relax themselves in a third zone by three-body recombination and ionisation. Finally, the formed plasma expands via the expansion zone towards the inter-electrode zone. We use a similar steady state model of the cathodic fragment where we only consider the sheath zone, the cathode, and its surface.

In section II, we compare the experimental measurements of ion density and ion velocity to the predictions of the simple two-fluid model of plasma sheath. In section III, we present the governing equations taking into account the term source in describing the dynamical sheath. In section IV numerical calculations of the sheath thickness and ion energy at wall are presented. In section V, we have treated a contribution to study of cathode erosion of plasma torch.

II- SHEATH MODEL DESCRIPTION

We consider an unmagnetized[Godyak and Stenberg], charge-neutral plasma in contact with a planar wall as sketched in figure(1). In the plasma both the density of electron n_e and the density of ion n_i are equal to the plasma density n_0 . The potential in the sheath is ϕ, and

the wall is held at a negative potential ϕ_w. Consequently, a sheath forms to separate the plasma from the wall [1].

Ions enter the sheath from the left as a cold beam with a velocity v_0 and strike the wall with a velocity v_w, and a kinetic energy $1/2\,Mv_w^2$ (figure 1) . Ions experience a collisional drag inside the Sheath. The boundary between the plasma and the sheath is at $x=0$, and the sheath thickness is D. That is the wall is at $x=D$. In partially ionised plasma, several important elastic and inelastic processes can take place simultaneously [4]. Elastic collisions involve only an exchange of momentum and energy between colliding particles where as inelastic processes such as ionisation, recombination, charge-exchange collision, secondary emission, sputtering etc. can be responsible for redistributing the number density, momentum and energy of the particles

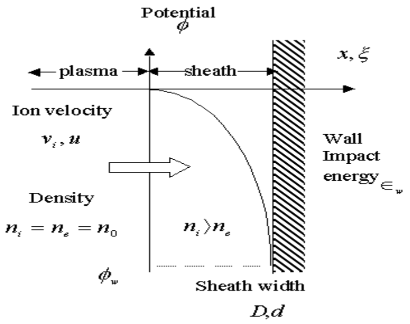

figure 1: Model system for the sheath [4,1]. The potential ϕ is sketched as a function of the distance x from the wall. Dimensionless quantities are shown to the right of their dimensional counterparts for most variables.

III-THE DYNAMICAL GOVERNING EQUATIONS IN PLASMA SHEATH

We consider governing equations based on a two-fluid model. The electrons are thermalized so their density obeys the Boltzmann relation [1],

$$n_e = n_0 \exp\left(\frac{e\phi}{K_B T_e}\right) \tag{1}$$

where e is the elementary charge, K_B is Boltzmann's constant, and T_e is the electron temperature. The cold ions obey the source-free, steady state equation of continuity,

$$\nabla.(n_i v_i) = 0 \tag{2}$$

and equation of motion,

$$M(v_i.\nabla)v_i = -e\nabla\phi - F_c \tag{3}$$

where the velocity and mass of the ions are v_i and M, respectively. As the ion fluid travels through the sheath it experiences a drag force

$$F_c = M(n_n \sigma v_i)v_i \tag{4}$$

where n_n is the neutral gas density and σ is the momentum transfer cross section for collisions between ions and neutrals. Elastic and change-exchange collisions contribute to this cross section [1], which depends on the ion speed v_i. Finally, Poisson's equation relates the electron and ion densities to the self-consistent potential:

$$\varepsilon_0 \nabla^2 \phi = -e(n_i - n_e) \tag{5}$$

where ε_0 is the permittivity constant.

To complete the model we must specify the dependence of the cross section on ion energy .we assume that it has a power law dependence on the ion speed of the form

$$\sigma(v_i) = \sigma_s \left(\frac{v_i}{c_s}\right)^{\gamma} \tag{6}$$

where $c_s = \sqrt{(K_B T_e / M)}$ is the ion acoustic speed, σ_s is the cross section measured at that speed, and γ is a dimensionless parameter ranging from 0 to -1

Combining Eqs.(1)-(6), we find two coupled, differential equations describing the planar plasma sheath [1]:

$$v_i \frac{dv_i}{dx} = -\frac{e}{M}\frac{d\phi}{dx} - n_n \sigma_s \frac{v_i^{2+\gamma}}{c_s^{\gamma}} \tag{7a}$$

$$\frac{d^2\phi}{dx^2} = -\frac{en_0}{\varepsilon_0}\left[\frac{v_0}{v_i} - \exp\left(\frac{e\phi}{K_B T_e}\right)\right] \tag{7b}$$

Equation (7a) is the equation of motion for the ion fluid, and Eq.(7b) is Poisson's equation for the electrical potential. The ion density can be calculated from the ion velocity using the equation of continuity [Eq(2)],and the electron density can be found the potential using the Boltzmann relation [Eq(1)]. With the addition of source terms, these equations would describe the entire discharge.

III-1/ Nondimensional variables

The governing equations can be made dimensionless by an appropriate choice of variables. The electric potential ϕ is scaled by the electron temperature,

$$\eta \equiv -e\phi / K_B T_e \tag{8a}$$

the distance x is scaled by the Debye length

$$\lambda_D = \sqrt{\left[\varepsilon_0 K_B T_e / (n_0 e^2)\right]},$$

$$\xi \equiv x/\lambda_D \tag{8b}$$

and the ion velocity V_i is scaled by the ion acoustic speed,

$$u \equiv v_i / c_s \tag{8c}$$

Additionally, the ion kinetic energy is made dimensionless by the electron thermal energy

$$\in \equiv \frac{1}{2}\left(Mv_i^{\,2} / K_B T_e\right) = \frac{1}{2}u^2 \qquad (8d)$$

so that the dimensionless ion impact energy at the wall is

$$\in_w = \tfrac{1}{2}u_w^2 \qquad (8e)$$

where u_w is the dimensionless ion velocity at the wall. The dimensionless sheath width is $d = D/\lambda_D$, and the dimensionless entry velocity is $u_0 = v_0 / c_s$.

The degree of collisionality in the sheath is parameterised by α , which is given by the number of collisions in a Debye length [1]**:**

$$\alpha = \lambda_D n_n \sigma_s \qquad (8f)$$

III-2/ The governing equations without term source

After the dimensionless variables in Eqs.(8a)-(8c) and Eq.(8f) are substituted into the governing equations [Eqs (7)], those equations become [1]:

$$uu' = \eta' - \alpha u^{2+\gamma} \qquad (9a)$$

$$\eta'' = u_0/u - \exp(-\eta) \qquad (9b)$$

where the prime denotes differentiation with respect to the spatial coordinate ξ, so that η' is the dimensionless electric field. As before, Eq.(9a) represents the conservation of ion momentum, and Eq.(9b) is Poisson's equation.

III-3/ The governing equations of dynamical in sheath with a term source

III-3-a/ The continuity equation

$$\nabla.(n_i v_i) = S_{ionization} - S_{recombinaiton} \qquad (10)$$

with

$$S_{ionization} = k_i n_n .n_e \qquad (11a)$$

and

$$S_{recombination} = k_{rec} n_i .n_e \qquad (11b)$$

where k_i is the rate of ionisation

and k_{rec} is the rate of recombination in sheath

the equation of motion:

$$M(v_i.\nabla)v_i = -e\nabla\phi - F_c \qquad (12)$$

where the velocity and mass of the ions are v_i and M ,respectively. As the ion fluid travels through the sheath it experiences a drag force:

$$F_c = M(n_n \sigma v_i)v_i \qquad (13)$$

III-3-b/ The Poisson equation

$$\varepsilon_0 \nabla^2 \phi = -e(n_i - n_e) \qquad (14)$$

after the substitution of the dimensionless variables in equations (11a),(11b) and (11c), those equations in sheath become:

$$uu' = \eta' - \alpha u^{2+\gamma} \qquad (15a)$$

$$n_i' = -\frac{\eta' n_i}{u^2} + \alpha n_i u^{\gamma} + \frac{k_i n_n \lambda_D}{u c_s} n_{e0} \exp(-\eta) \qquad (15b)$$

$$- \frac{k_{rec} n_i \lambda_D}{u c_s} n_{e0}^{\;2} \exp(-2\eta)$$

$$\eta'' = \frac{n_i}{n_{e0}} - \exp(-\eta) \qquad (15c)$$

In our simulation, we have considered that $k_i = 1.5 \cdot 10^{-10}$ and $k_{rec} = 10^{-12}$, γ is a parameter, which varies between –1 and 0 , and α is collision parameter ranging between 0 and 10.

IV- SIMULATION

In order to study the effect of collision on the sheath thickness and impact energy, we have solved the governing equations in two cases : without term source [Eqs. (9)] and with term source [Eqs.(15)] by using the numerical Runge-Kutta routine. To solve these equations boundary conditions must be specified. At the wall $(\xi = d)$ the boundary conditions are $\eta(d) = \eta_w$. At the sheath-plasma boundary $(\xi = 0)$ the boundary conditions are $\eta(0) = 0$, $\eta'(0) = 0$ and $u(0) = u_0$.

A two-fluid model reveals the effects of ion collisionality on the plasma sheath. Exact numerical solutions of the model are used to determine the collisional dependence of the sheath width and the ion impact energy at the wall.

V- RESULTS AND COMMENTS

In the following figures, we plot the sheath thickness d and the ion impact energy $\in_w$ as the function of the collision parameter α and wall the potential η_w . These plots show two regimes of sheath collisionality. For small α, collisions are negligible, and both d and $\in_w$ are nearly independent of α. For large α ,the ion motion is colisionally dominated; both d and $\in_w$ decrease and approach the power law of asymptotes.

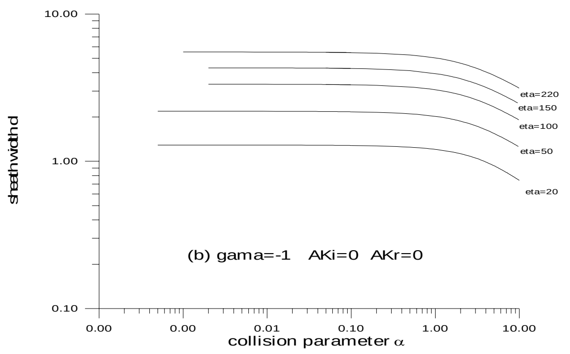

figure 2: Exact numerical solutions of the governing equations [Eqs.(9)] for the dimensionless sheath thickness d as a function of the collision parameter α for various wall potentials η_w. In this figure (b) we show results without terms source for $\gamma = -1$(constant mobility). Two regimes are evident: a collision less regime (α small) where d is nearly independent of α,a collisionally dominated regime (α large) where d approaches a limiting asymptote.

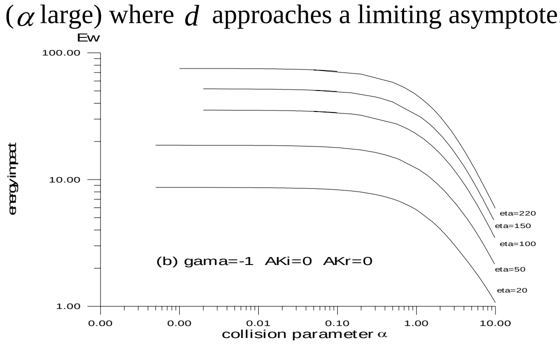

figure 3: Exact numerical solution for the average ion energy at impact on the wall $\in_w$ as a function of the collision parameter α for various wall potentials η_w. In this figure (b) we shows results without terms source of the constant on mobility for $\gamma = -1$. Two regimes are evident: a collision less regime (α small) where $\in_w$ is nearly independent of α , a collisionally dominated regime (α large) where $\in_w$ approaches a limiting asymptote.

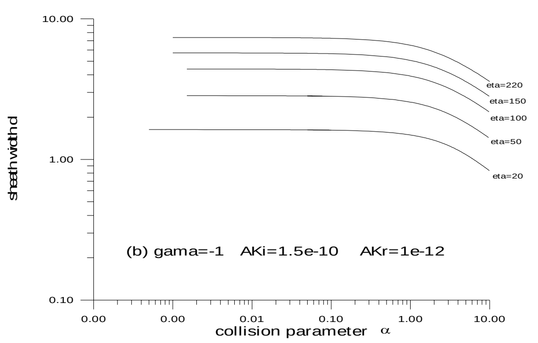

figure 4: The following figure states the exact numerical solutions of the governing equations [Eqs.(15)] for the dimensionless sheath thickness d as a function of the collision parameter α for various wall potentials η_w. In this figure (b) we show the results for $\gamma = -1$(constant mobility) with the terms source. Two regimes are evident: a collision less regime (α small) where d is nearly independent of α and a collisionally dominated regime (α large) where d approaches a limiting asymptote.

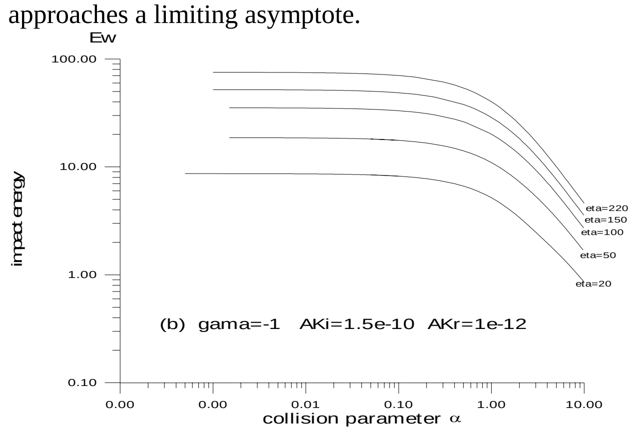

figure 5: Illustrate the exact numerical solution for the average ion energy at impact on the wall $\in_w$ as a function of the collision parameter α for various wall potentials η_w with the terms source. In this figure (b) we show results for $\gamma = -1$. Two regimes are evident: a collision less regime (α small) where $\in_w$ is nearly independent of α and a collisionally dominated regime (α large) where $\in_w$ approaches a limiting asymptote.

VI-THE EROSION OF THE CATHODE SHEATH OF AN ELECTRICAL ARC

In this article, we propose the modelling of the physical phenomena occurring on the cathode surface and in the sheath. The goals are to obtain the characteristic values of the heat flux, the cathode heating derived from the plasma bombardment (ions, electrons, atoms, radiation) on the surface and the Joule effect in the bulk. The energy is dissipated by thermal conduction, surface vaporization and droplet ejection, inducing the creation of a crater on the electrode surface (figure 6). The cathode surface represents the interface between the cathode and the plasma in the vicinity of the electrode where the main phenomena occur : the electronic emission, the atomic evaporation, and the ionic bombardment. Above the sheath, the electron energy is enough to ionise particles inducing electron relaxation. A part of the newly created ions moves towards the surface, accelerated by the drop potential in the sheath [5]. The ion velocity is reduced by ionic friction between the ions bombarding the surface and the vaporized atoms; this leads to a heat flux regulation.

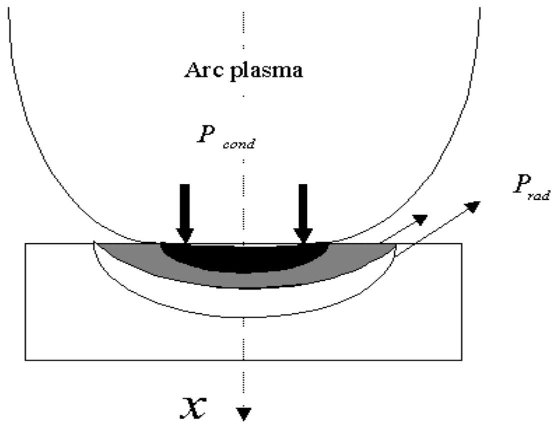

figure 6 : Geometry used for the heat transfer model .

VI- The surface and the sheath modelling

In order to estimate the spot's characteristics (density, velocity of the species, heat flux), we adopt a one-dimensional model of the cathodic spot, as proposed by Beilis, where we neglect the droplet ejection. The cathode surface plane, and the Ox axis (positively oriented toward the cathode) are perpendicular to the surface. We assume that all the physical variables (density , velocity, potential,...)depend only on the x coordinate and we suppose a steady process [5].
In the sheath, the model is based on conservation laws (density, impulsion, energy flux conservation),adding the interaction terms (ionic friction) [5]. The electrostatic interaction in the sheath is taken into account by solving the Poisson equation. The sheath is composed of ions, atoms, and electrons, where we distinguish between the thermo emitted electrons and the electrons coming from the plasma. Since we have a one-dimensional model, the vector valued functions like the velocity only have a component following the Ox axis , and , for the sake of simplicity, we denote by $v_{eo}(x), v_e(x), v_i(x)$,and $v_n(x)$ respectively the thermo-emitted electron, the plasma-emitted electron, the ions, and the mean atomic velocity following the Ox component; $J_\alpha(x), \alpha = eo, e, i$ represent the current density flux and $n_\alpha(x)$is the particle density of each kind. We also note by Γ_n the atom density flux . We evaluate on the surface the different energy transfer between the cathode and the particles and we obtain a first relation linking the vaporized energy flux to the heat flux on the cathode surface. Using an enthalpy model to describe the energy evolution of the cathode bulk, we obtain a second relation between the heat flux and the vaporized energy flux [5]. Thanks to the equilibrium assumption, we obtain numerical evaluations of the characteristic variables of the sheath zone.

VI-1- The bombardment of the electrons

We introduce the Bohm criterion [6] in order to determine the ionic velocity and the electron density. At the sheath bottom we model the particle emissions supplying the sheath zone using the thermo electronic emission and the Langmuir vaporization. Under the steady state assumption[1], the electron density function is given by

$$n_e(x) = n_{e0} \exp\left(-e \frac{\phi - \phi(x)}{K_B T_e} \right) \qquad (16)$$

Where ϕ and n_{e0} are the voltage and the electron density in the plasma.
Bohm postulates that the cathode sheath is stable in order to evaluate the ion distribution in the electric arc and show that we obtain a stable sheath if we respect the inequality [5]:

$$e(\phi - \phi_w) \geq \frac{K_B T_e}{2} \qquad (17)$$

This implies that the kinetic energy of the ions in the sheath edge is greater than $\frac{K_B T_e}{2}$
thus the ion velocity satisfies the inequality

$$v_i(x) \geq \sqrt{\frac{K_B T_e}{M}} \qquad (18)$$

where the thermo emitted electrons are neglected. At the sheath edge, we evaluate the ionic density flux

$$J_i(0) = e n_i(0) v_i(0) = e n_e(0) \sqrt{\frac{K_B T_e}{M}} \qquad (19)$$

Since we assume J_i is constant in the sheath, we obtain an evaluation of J_i in the whole domain. Another consequence derived from the Bohm criterion is the ion velocity evaluation. Indeed, the energy conservation law yields

$$\frac{1}{2} M \left(v_i^2(x) - v_i^2(0) \right) = Ze(\phi - \phi(x)) \qquad (20)$$

where Z is the ionisation number. From the Bohm criterion and the fact that the ions go toward the cathode, we deduce

$$v_i(x) = -\left(\frac{2Ze(\phi_w - \phi(x)) + K_B T_e}{M} \right)^{\frac{1}{2}} \qquad (21)$$

and the ion density $n_i(x) = |J_i| / |e v_i(x)|$.

VI-1/a- Electronic emission

The Bohm criterion gives information about the ions and electrons issued from the plasma, but we also have to consider those coming from the cathode in order to evaluate the electric potential ϕ. The drop potential in the sheath and, at the sheath edge accelerates electrons emitted by the surface, the electrons have enough energy to ionise the atoms. Some of them return towards the surface since the other part constitutes a plasma surrounding the spot. We first evaluate the emitted flux

electron and the associated extraction energy. Then we estimate the power density of the electrons returning towards the surface [5].
Murphy and Good proposed in [7] an expression of the constant emitted electron density current J_{eo} at the cathode surface by the thermo electronic emission with field effect (T.F) where the electric field E_s and the temperature T_s on the cathode surface are the main parameters :

$$J_{eo} = -e\int_{-W_a}^{\infty} D(W,E_s)N(W,T_s)dW \qquad (22)$$

where W_a represents the electron potential energy in the metal and the function $D(W,E_s)$ is the emission probability for an electron with energy W , from the surface material submitted to an electric field E_s and surface temperature T_s. $N(W,T_s)dW$ represents the number of electrons knocking the potential barrier per unit area. As we mentioned above, we use a numerical method to evaluate J_{eo} (a classical integration method like the Simpson method, for example) but in the case of a copper cathode a simplification of the Murphy Good formula is if $E_s \in [10^8, 10^{10} V/m]$ and $T_s \in [300, 4000K]$

$$J_{eo}(E_s,T_s) \approx \frac{4\pi m_e kT_s}{h^3} e\int_{W_1}^{W_2} \ln\left(1+\exp\left(-\frac{W+\phi}{k_B T_s}\right)\right)dW \qquad (23)$$

with $W_1 = -\sqrt{\frac{e^3 E_s}{4\pi\varepsilon_0}}$ and $W_2 = 5eV$

where the emitted electron density current [8] is given by :

$$J_{eo} = \frac{4\pi m_e (kT_s)^2 e}{h^3} \exp\left(-\frac{e\phi}{K_B T_e}\right) \qquad (24)$$

VI-1/b- The returning electrons

The cathode-emitted electrons ionise the atoms above the sheath, and some electrons returns to the plasma. Like Beilis [3], we assume a Maxmellian distribution of the returning electron velocity centred to mean velocity v_m [5]. Due to the drop potential V_s at the sheath an electron situated at the top of the sheath reaches the cathode if its vertical velocity satisfies

$$v_x \langle v_{e\min} = -\sqrt{\frac{2eV_s}{m_e}} \qquad (25)$$

At the cathode surface, the electron density is given by

$$n_e(d) = n_e(0)\exp\left(-\frac{eV_s}{K_B T_e}\right) \qquad (26)$$

VI-2-Atomic emission and bombardment

The heating flux on the cathode induces a local vaporization of the cathode and an emission of atom. A small portion returns to the cathode, but, according to the bibliography(see Hanztsche [9]), we consider that atomic bombardment is negligible in comparison with ionic bombardment. In the following, we consider that the atom-emitted flux remains constant since no ionisation occurs in the sheath. The main cooling source of the cathodic surface is the atomic emission depending on the local thermal excitation of the electrode. Two situations are considered : whether the surface temperature is lower than the vaporization temperature or equal [5].
In the first case, the atomic emission on the surface is governed by a probability law based on the equilibrium between the surface and the surrounding vapour (Langmuir evaporation). The atom-emitted flux is given by :

$$\Gamma_n = n_0\sqrt{\frac{K_B T_s}{2\pi m_n}} \qquad (27)$$

where the emitted neutral density n_0 is given by (see Vilain and al [10]):

$$n_0 = \left(\frac{m_n K_B T_s}{2\pi\hbar^2}\right)^{3/2} \exp\left(\frac{-W_{coh}}{K_B T_s}\right) \qquad (28)$$

with W_{coh} the cohesion energy. Denoting by W_{ev} the evaporate energy, we define the vaporized power flux (see Mitterauer [11])

$$P_{vap} = \Gamma_n(2K_B T_s + W_{ev}) \qquad (29)$$

The second case occurs when the surface temperature tends towards the vaporization temperature. The vaporized power flux P_{vap} at the cathode surface becomes the atom density flux leaving the cathode multiplied by the vapour enthalpy [5]. Vaporization is also the limit case of the Langmuir emission where the density $n_0 = n_n(0)$ represents the atom density on the surface thus

$$P_{vap} = n_n(0)\sqrt{\frac{K_B T_s}{2\pi m_n}}(2K_B T_s + W_{ev}) \qquad (30)$$

VI-3- The ionic bombardment

The ionic bombardment on the cathode surface is the energy flux of the ions falling on the surface P_i (see Beilis, Mitterauer ,Handbookhantzsche, Zhou [3,11,9,12]). It represents the main contribution of the

energy flux across the surface. P_i is the product of the ionic flux J_i by the mean energy deposited by an ion on the surface [13,9,11,12].

The ionic mean energy at the surface is composed of the ionic kinetic energy at the edge sheath evaluated by the Bohm criterion (see [7]), the drop potential, and the neutralization energy reduced by the work function modified by the presence of the high electric field E_s on the surface (see Schottky [14]).

Finally, the ion reaching the surface condenses in the electrode and gives the energy W_{ev} [11].the ionic power density is :

$$P_i = \left(e\phi_w + \frac{K_B T_e}{2} + \phi_i - \phi + \sqrt{\frac{e^3 E_s}{4\pi\varepsilon_0}} + W_{ev} \right) \qquad (31)$$

VI-4 -The energetic balance

The steady state assumption implies that the surface its in an energetic equilibrium between the energy gain and loss during the spot lifetime. The plasma and the cathode surface emit electromagnetic radiations that are negligible in comparison with the heat flux, and the Joule effect, created by the electronic current, is negligible in comparison with the ionic bombardment [5] . On the cathode surface, the equilibrium condition [15] is given by the relation:

$$P_i = P_{eo} + P_{cond} + P_{vap}$$

(32)

P_i is due to ionic bombardment on the cathodic surface.

P_{vap} represents power dissipated by material evaporation:

$$P_{vap} = DG_s' \qquad (33)$$

where G_s' is the mass loss per unit time and D is the energy needed for evaporation of unit mass of material (graphite) ($D = 59\times10^6\, J.Kg^{-1}$)

P_{cond} represents power dissipated by thermal conduction through the spot. To calculate this power , we assume that the cathode material is a semi-infinite solid (see Lefort [15]) and that the steady state is quickly reached for thermal flow.

$$P_{cond} = (T_s - T_0) K\pi^{3/2} r_s$$

(34)

T_0 is the room temperature and K is the material thermal conductivity ($K = 10W.m^{-1}.K^{-1}$) and r_s is the cathode spot radius

P_{eo} is the electron emitted flux

where

$$P_{eo} = \frac{J_{eo}}{e}\left(\phi - \sqrt{\frac{e^3 E_s}{4\pi\varepsilon_0}} \right) \qquad (35)$$

VII- RESULTS AND COMMENTARY

The reported results were obtained by using the cathode spot plasma conditions which are based on graphite. The value of the graphite cathode D is the energy needed for the evaporization of the unit mass of material $D = 59\times10^6\, J.Kg^{-1}$ and K is the material thermal conductivity $K = 10W.m^{-1}.K^{-1}$.

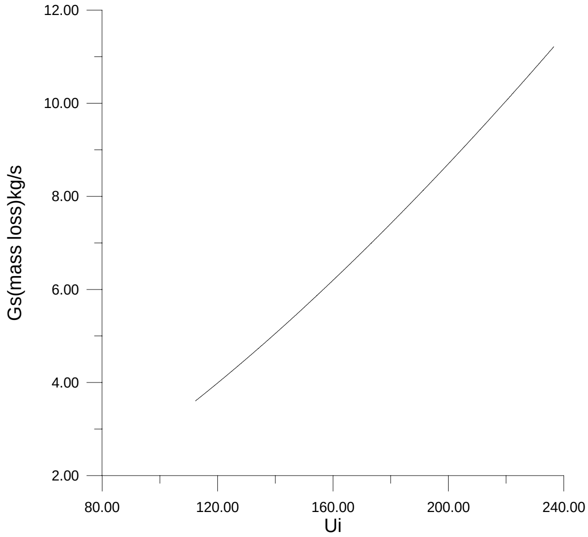

figure 7 : Mass loss per unit time as a function of the ion velocity .

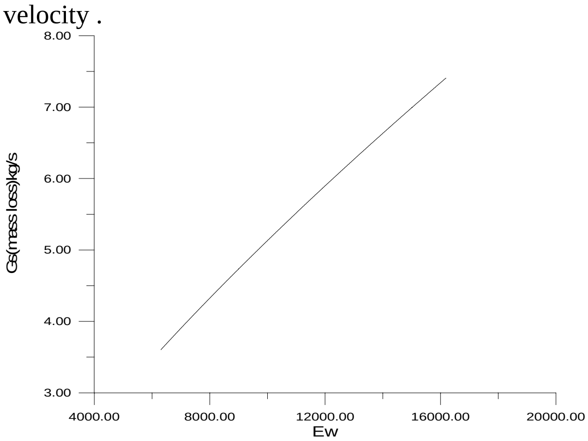

figure 8 : Mass loss per unit time as a function of the energy impact.

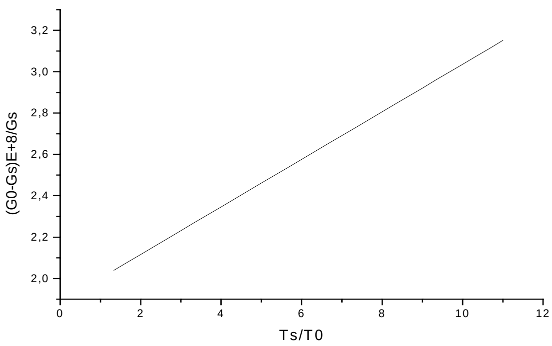

figure 9 : The fractional mass loss per unit time as a function of the fractional surface temperature for eta=10,gama=-1 and T_0=300K.

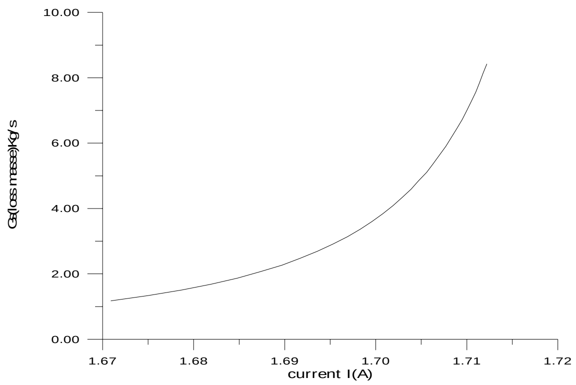

figure 10 : Mass loss per unit time of the cathode Gs as a function of the current I(A).

The figure (7), we plot the variation of the mass loss per unit time as a function of the ionic velocity . Note that the erosion rate of cathode increases linearly when the ion velocity increases.

the figure (8) represents the linear variation of the mass loss per unit time as a function of the ion energy impact on the wall (cathode). in this figure ,we show that the erosion rate of the cathode increases when the ion energy deposited by an ion on the surface increases.

The initial cathode temperature is allowed to change from 300 to 4000 K in order to represent the fractional mass loss per unit time as a function of the fractional surface temperature (figure 9), for instance, that the erosion rate increases if the temperature on the cathode surface increases. The results presented in figure (10) clearly show that the variation of the mass loss per unit time as a function the current density of ion bombardment on the cathode surface. The erosion rate by atomic vaporization depends strongly on the current, the plot reveals good agreement qualitatively with the results obtained by the author [15].

VIII- Conclusion

In order to study the effect of collisions on the sheath thickness and impact energy, we have showing that the collision reduce the impact energy and decreasing the sheath width. In this article, we proposed a method of obtaining the physical characteristics of a fragment in the cathode.

The theoretical modelling based on the steady state assumption uses the coupling of the cathode heating model and sheath model.

A comparison of our results with the measurement obtained by another group showed the good prediction accuracy of the experimental model [15] results and the theoretical model [4,1].

The results of our simulation can be applied to study the erosion rate and the lifetime of the cathode for various material.

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