THERMAL ANALYSIS OF THE INFLUENCE OF THE SUPPORT IN THE SUPERFICIAL TREATMENT BY PLASMA OF CYLINDRICAL SAMPLES

Belisio A. S, abelisio@yahoo.com.br
Lima J.A., jalima@dem.ufrn.br
Alves Jr. C alvesjr@dem.ufrn.br

Universidade Federal do Rio Grande do Norte
Programa de Pós-Graduação em Engenharia Mecânica
Av. Senador Salgado Filho, SN – Lagoa Nova
Natal, RN – 59072-290

Abstract. *Different of the conventional processes of heating, that is, transport, convection, and radiation, heat transfer in heating process by plasma also occur also by collisions of particles, in other words, through the transfer heat motion ions for the surface of the sample, the kinetic energy, and potential those particles, as well as the enthalpy of the chemical reactions involved in the surface. In thermal plasmas, that transfer can to be simplified initially through general energy balance between plasma and samples. However, existent models of temperature distribution are in its majority unidimensionais and it do not analyze, mainly, support influence on sample in the heating process byr plasma. In that way, with the mark of analyzing the temperature distribution in the samples submitted to polarization voltage of 706 V, 744 V and 790 V, as well as porcess heating support influence analysis those samples, the present work developed a code computacional for a transient (2D-t) two-dimensional model, destined to the simulationof the heat transfer during heating phases and cooling in superficial process of treatment by plasma in cylindrical samples of copper, being considered the configuration of hollow cathode and the presence of a support. The model computacional serves as a tool in the predict of the final properties of treated samples, well as in the specification of the parameters of the heating processes by plasma. In the developed model was considered that the physical samples properties were variable, functions of the temperature field. The results obtained through simulation are leaning and validated in experimental and theoretical data available in the literature, as well as, in information of tests accomplished in LabPlasma / UFRN.*

Keywords*: Plasma Heating,, Treatmet Surface, Computational Simulation, Finite Volume Methods.*

1. INTRODUCTION

According to Bellan (2004), in the 20's and 30's, of the century last, few isolated researchers, each motivated by specific practical problems, began the study of what now called plasma physics. According to Alves Jr. et al. (2001), the plasma nitriding is an advanced technology of modification of surfaces and has been employed in an increasing number industrial development in the last 30 years. The technological progress, mainly the related to the electronics, automation and computerization, allowed, starting from the end of the century XX, the full development of the plasma technology.

In this presence context appear the need to development of experimental and theoretical studies, with large or smaller degree of characterization detail, be able realize thermal simulations effects of plasma in samples treated by the same. Therefore, as form of contributing in that research field and technological application, the present work has the objective at to study and to temperature distribution analyze in metallic samples of solids immersed in plasma, considering several factors intrinsic presents in experimental apparatus of the Laboratory of Plasma, LabPlasma / UFRN.

In that sense, a two-dimensional model was developed destined to simulation of transfer of heat during the heating phases, and cooling of the heating process for plasma, being considered the configuration hollow cathode. The model computational will serve as other tool in the forecast of the final properties of the treated samples, as well as, hereafter, in the specification of the parameters of the heating process for plasma. In the developed model was considered that the physical properties of samples (specific mass, specific heat and thermal conductivity) were variable, functions of the temperature field.

The results obtained in the simulation are validated in experimental and theoretical data available in the literature, as well as, in information of tests accomplished in LabPlasma / UFRN.

2. MATHEMATICAL MODEL

Being taken into account that support of the sample also participates and has influence in the process heat transmission, the model considers that energy can to be transferred so much in a direction along the longitudinal axis as in a direction along the radial axis in the two geometries, but still under angular symmetry. The Fig. 1 shows the outline of the two-dimensional model, which illustrates the hollow cylinder used to simulate the effects of the configuration hollow cathode.

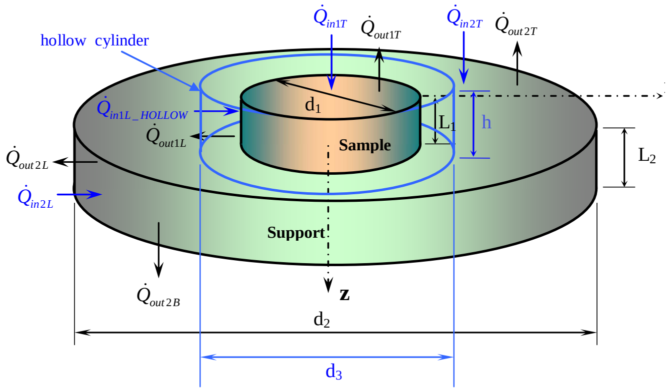

Figure 1. Schematic draw of two-dimensional model: support and sample for the hollow cathode effect.

Such hypotheses characterize a transient (2D-t) two-dimensional model in two domains (sample and support), in the cylindrical (r, z, t) coordinates, that it can to have different thermal characteristics, acted for following equations:

$$\rho_i(T)c_{pi}(T)\frac{\partial T_i(r,z,t)}{\partial t}=\frac{1}{r}\frac{\partial}{\partial r}\left[rk_i(T)\frac{\partial T_i(r,z,t)}{\partial r}\right]+\frac{\partial}{\partial z}\left[k_i(T)\frac{\partial T_i(r,z,t)}{\partial z}\right]; \qquad \begin{matrix}0<r<R_i\\ 0<z<L_i\\ i=1,2\end{matrix}, \quad t>0 \tag{1}$$

The equations of heat transport above are submitted to the initial conditions:

$$T_i(r,z,0)=T_{ini}; \qquad t=0, \quad \begin{matrix}0\le r\le R_1\\ 0\le z\le L_1\\ i=1,2\end{matrix} \tag{2}$$

Therefore, the boundary conditions are written being observed that the position $z = \boldsymbol{L_1}$ characterizes the interface among the two domains. The equations for that position was written being assumed perfect (temperature equality and of flow of heat) contact in the interface sample / support.

In axis of symmetry of the sample and of the support:

$$-k_i\left.\frac{\partial T_i(r,z,t)}{\partial r}\right|_{r=0}=0; \qquad \begin{matrix}0<r<R_i\\ 0<z<L_i\\ i=1,2\end{matrix}, \quad t>0 \tag{3}$$

In vertical lateral surface of the sample:

$$-k_1\left.\frac{\partial T_1(r,z,t)}{\partial r}\right|_{r=R_1}=\frac{\dot{Q}_{in1L\_HOLLOW}-\dot{Q}_{out1L}}{A_{1L}}; \qquad \left.\begin{matrix}r=R_1\\ 0\le z\le L_1\end{matrix}\right\}, \quad t>0 \tag{4}$$

In vertical lateral surface of the support:

$$-k_2\left.\frac{\partial T_2(r,z,t)}{\partial r}\right|_{r=R_2}=\frac{\dot{Q}_{in2L}-\dot{Q}_{out2L}}{A_{2L}}; \qquad \left.\begin{matrix}r=R_2\\ L_1\le z\le L_2\end{matrix}\right\}, \quad t>0 \tag{5}$$

In surface horizontal superior of the sample:

$$-k_1\left.\frac{\partial T_1(r,z,t)}{\partial z}\right|_{z=0}=\frac{\dot{Q}_{in1T}-\dot{Q}_{out1T}}{A_1}; \qquad \left.\begin{matrix}z=0\\ 0\le r\le R_1\end{matrix}\right\}, \quad t>0 \tag{6}$$

In interface sample / support:

$$\left.\begin{matrix}T_1(r,L_1,t)=T_2(r,L_1,t)\\ -k_1\left.\dfrac{\partial T_1(r,z,t)}{\partial z}\right|_{z=L_1}=-k_2\left.\dfrac{\partial T_2(r,z,t)}{\partial z}\right|_{z=L_1}\end{matrix}\right\}; \qquad \left.\begin{matrix}z=L_1\\ 0\le r\le R_1\end{matrix}\right\}, \quad t>0 \tag{7-8}$$

$$-k_2 \left.\frac{\partial T_2\left(r,z,t\right)}{\partial z}\right|_{z=L_1} = \frac{\dot{Q}_{in2T}-\dot{Q}_{out2T}}{A_2-A_1}\ ; \qquad \left.\begin{matrix} z=L_1 \\ R_1\le r\le R_2\end{matrix}\right\}, \quad t>0 \tag{9}$$

In surface horizontal inferior of the support:

$$-k_2 \left.\frac{\partial T_2\left(r,z,t\right)}{\partial z}\right|_{z=L_2} = \frac{\dot{Q}_{out2B}}{A_2}\ ; \quad \left.\begin{matrix} z=L_2 \\ 0\le r\le R_2\end{matrix}\right\}, \quad t>0 \tag{10}$$

In agreement with the equations, two terms of incident energy should be specified, one in that the incidence is direct on the area of the traverse section, $\dot{Q}_{in1T}$, and the another in that the incidence is indirect on the lateral surface of the sample (effect hollow cathode), $\dot{Q}_{in1L\_HOLLOW}$. Also, besides the losses of heat in superior surface, $\dot{Q}_{out1T}$, and in the inferior surface, $\dot{Q}_{out1B}$, the influence the losses of heat can be evaluated in the lateral surface of the sample, $\dot{Q}_{out1L}$.

According to Kersten et al. (2001), the incident heat flow on the superior surface and support, $\dot{Q}_{inT1}$, it should take into account the gain of energy due to effects plasma radiation source, $\dot{Q}_{rad}$, of the load transporters (electrons and ions) , $\dot{Q}_{ch}$, of the neutral species, $\dot{Q}_{n}$, and of another external sources , $\dot{Q}_{ext1T}$.

In upper surface of the sample:

$$\dot{Q}_{in1T} = \dot{Q}_{rad} + \dot{Q}_{ch} + \dot{Q}_{n} + \dot{Q}_{ext1T}\ ; \quad \left.\begin{matrix} z=0 \\ 0\le r\le R_1\end{matrix}\right\}, \quad t>0 \tag{11}$$

$$\dot{Q}_{rad} = \sigma A_1\left[\varepsilon_{rad}T_{rad}^4 - \varepsilon_1 T_1^4\left(r,0,t\right)\right] \tag{12}$$

$$\dot{Q}_{ch} = A_1\left[\, j_i\left(E_{ion} + \delta e_0 V_{bias} + \delta e_0 V_i\right) + j_e E_e\right] \tag{13}$$

$$\dot{Q}_{n} = A_1 R_{dep}\frac{N_A\rho}{M}E_n \tag{14}$$

$$\dot{Q}_{out1T} = \dot{Q}_{rad} + \dot{Q}_{cond} + \dot{Q}_{conv}\ ; \qquad \left.\begin{matrix} z=0 \\ 0\le r\le R_1\end{matrix}\right\}, \quad t>0 \tag{15}$$

$$\dot{Q}_{rad} = \sigma A_1\left[\varepsilon_1 T_1^4\left(r,0,t\right) - \varepsilon_{amb}T_{amb}^4\right] \tag{16}$$

$$\dot{Q}_{cond} = \alpha\,\chi\,P\,A_1\left[T_1\left(r,0,t\right) - T_g\right] \tag{17}$$

$$\dot{Q}_{conv} = h\,A_1\left[T_1\left(r,0,t\right) - T_g\right] \tag{18}$$

In upper surface of the support:

$$\dot{Q}_{in2T} = \dot{Q}_{rad} + \dot{Q}_{ch} + \dot{Q}_{n} + \dot{Q}_{ext2T} \qquad \left.\begin{matrix} z=L_1 \\ R_1\le r\le R_2\end{matrix}\right\}, \quad t>0 \tag{19}$$

$$\dot{Q}_{rad} = \sigma\left(A_2 - A_1\right)\left[\varepsilon_{rad}T_{rad}^4 - \varepsilon_2 T_2^4\left(r,L_1,t\right)\right] \tag{20}$$

$$\dot{Q}_{ch} = \left(A_2 - A_1\right)\left[\, j_i\left(E_{ion} + \delta e_0 V_{bias} + \delta e_0 V_i\right) + j_e E_e\right] \tag{21}$$

$$\dot{Q}_{n} = \left(A_2 - A_1\right)R_{dep}\frac{N_A\rho}{M}E_n \tag{22}$$

$$\dot{Q}_{out2T} = \dot{Q}_{rad} + \dot{Q}_{cond} + \dot{Q}_{conv}\ ; \qquad \left.\begin{matrix} z=L_1 \\ R_1\le r\le R_2\end{matrix}\right\}, \quad t>0 \tag{23}$$

$$\dot{Q}_{rad} = \sigma\left(A_2 - A_1\right)\left[\varepsilon_2 T_2^4\left(r,L_1,t\right) - \varepsilon_{amb}T_{amb}^4\right] \tag{24}$$

$$\dot{Q}_{cond} = \alpha\,\chi\,P\left(A_2 - A_1\right)\left[T_1\left(r,0,t\right) - T_g\right] \tag{25}$$

$$\dot{Q}_{conv} = h\left(A_2 - A_1\right)\left[T_1\left(r,0,t\right) - T_g\right] \tag{26}$$

In lateral surface of the sample:

$$\dot{Q}_{in1L\_HOLLOW} = \dot{Q}_{rad} + \dot{Q}_{ch} + \dot{Q}_n + \dot{Q}_{ext1L} \;; \qquad \left.\begin{array}{l} r = R_1 \\ 0 \le z \le L_1 \end{array}\right\}, \quad t > 0 \tag{27}$$

$$\dot{Q}_{rad} = \sigma A_{1L}\left[\varepsilon_{rad} T_{rad}^4 - \varepsilon_1 T_1^4\left(z, R_1, t\right)\right] \tag{28}$$

$$\dot{Q}_{ch} = A_{1L}\left[j_i\left(E_{ion} + \delta e_0 V_{bias} + \delta e_0 V_i\right) + j_e E_e\right] \tag{29}$$

$$\dot{Q}_n = A_{1L} R_{dep} \frac{N_A \rho}{M} E_n \tag{30}$$

$$\dot{Q}_{out1L} = \dot{Q}_{rad} + \dot{Q}_{cond} + \dot{Q}_{conv} \;; \qquad \left.\begin{array}{l} r = R_1 \\ 0 \le z \le L_1 \end{array}\right\}, \quad t > 0 \tag{31}$$

$$\dot{Q}_{rad} = \sigma A_{1L}\left[\varepsilon_1 T_1^4\left(z, R_1, t\right) - \varepsilon_{amb} T_{amb}^4\right] \tag{32}$$

$$\dot{Q}_{cond} = \alpha\, \chi\, P\, A_{1L}\left[T_1\left(z, R_1, t\right) - T_g\right] \tag{33}$$

$$\dot{Q}_{conv} = h_{1L}\, A_{1L}\left[T_1\left(z, R_1, t\right) - T_g\right] \tag{34}$$

In lateral surface of the support:

$$\dot{Q}_{in2L} = \dot{Q}_{rad} + \dot{Q}_{ch} + \dot{Q}_n + \dot{Q}_{ext2L} \;; \qquad \left.\begin{array}{l} r = R_2 \\ L_1 \le z \le L_2 \end{array}\right\}, \quad t > 0 \tag{35}$$

$$\dot{Q}_{rad} = \sigma A_{2L}\left[\varepsilon_{rad} T_{rad}^4 - \varepsilon_2 T_2^4\left(z, R_2, t\right)\right] \tag{36}$$

$$\dot{Q}_{ch} = A_{2L}\left[j_i\left(E_{ion} + \delta e_0 V_{bias} + \delta e_0 V_i\right) + j_e E_e\right] \tag{37}$$

$$\dot{Q}_n = A_{2L} R_{dep} \frac{N_A \rho}{M} E_n \tag{38}$$

$$\dot{Q}_{out2L} = \dot{Q}_{rad} + \dot{Q}_{cond} + \dot{Q}_{conv} + \dot{Q}_{ext2L} \;; \qquad \left.\begin{array}{l} r = R_2 \\ L_1 \le z \le L_2 \end{array}\right\}, \quad t > 0 \tag{39}$$

$$\dot{Q}_{rad} = \sigma A_{2L}\left[\varepsilon_2 T_2^4\left(z, R_2, t\right) - \varepsilon_{amb} T_{amb}^4\right] \tag{40}$$

$$\dot{Q}_{cond} = \alpha\, \chi\, P\, A_{2L}\left[T_2\left(z, R_2, t\right) - T_{amb}\right] \tag{41}$$

$$\dot{Q}_{conv} = h_{2L}\, A_{2L}\left[T_2\left(z, R_2, t\right) - T_{amb}\right] \tag{42}$$

Moreover, the support is also involved by the plasma, in the inside surface:

$$\dot{Q}_{out2B} = \dot{Q}_{rad} + \dot{Q}_{cond} + \dot{Q}_{conv} \;; \qquad \left.\begin{array}{l} z = L_2 \\ 0 \le r \le R_2 \end{array}\right\}, \quad t > 0 \tag{43}$$

$$\dot{Q}_{rad} = \sigma A_2\left[\varepsilon_2 T_2^4\left(L_2, r, t\right) - \varepsilon_{amb} T_{amb}^4\right] \tag{44}$$

$$\dot{Q}_{cond} = \alpha\, \chi\, P\, A_2\left[T_2\left(L_2, r, t\right) - T_g\right] \tag{45}$$

$$\dot{Q}_{conv} = h_{2B}\, A_2\left[T_2\left(L_2, r, t\right) - T_g\right] \tag{46}$$

where: $\sigma = 5.67\times10^{-8} Wm^{-2}K^{-4}$ denotes the Stefan-Boltzmann constant, ε is the emittance of radiation, χ is the free molecular heat conductivity , N_A is the Avogadro's number, M atomic mass, R_{dep} is the deposition arte, P pressure, ρ mass density, T temperature , T_g gas temperature, A area, h height ,and L thickness.

The analysis can to be simplified through the experimental specification of the global portions of energy that it enter and that it leave the sample, , $\dot{Q}_{in1T}$, $\dot{Q}_{in1L\_HOLLOW}$, $\dot{Q}_{out1T}$, $\dot{Q}_{out1L}$ e $\dot{Q}_{out1B}$. For that alternative, the gain of heat obtained experimentally, $\dot{Q}_{in}$, it should be divided among the portions $\dot{Q}_{in1T}$, $\dot{Q}_{in2T}$ and $\dot{Q}_{in1L\_HOLLOW}$, while the loss of experimental heat, $\dot{Q}_{out}$, it should be divided among the portions $\dot{Q}_{out1T}$, $\dot{Q}_{out1L}$, $\dot{Q}_{out2T}$, $\dot{Q}_{out2L}$ e $\dot{Q}_{out2B}$. He suggests that the relationships among the areas of the surfaces so much of gain, as of loss of heat, be the parameters more adapted for those divisions.

3 - METHODOLOGY OF SOLUTION

As first step for the validation of the code developed computational, a rigorous specification of the several portions that characterize the gain flows and loss of heat (the thermal characterization of the experimental assembly of the plasma) it can be avoided being made use of global experimental data of temperature of the heating processes cooling in samples. For that road, in agreement with Kersten et al., the gain of total heat that happens on a sample it can be obtained starting from the measuring of the rate of heating of the bombarded surface of the sample in the initial instant (swinging of energy in the instant $t = 0$):

$$\dot{Q}_{in} = \rho_S L_S A_S c_S \left.\frac{dT_S}{dt}\right|_{t=0} \tag{47}$$

In a simplified way and alternatively, the gain of heat obtained experimentally, $\dot{Q}_{in}$, it should be divided among the portions $\dot{Q}_{in1T}$ e $\dot{Q}_{in1L\_HOLLOW}$, while the loss of experimental heat $\dot{Q}_{out}$ it should be divided among the portions $\dot{Q}_{out1T}$, $\dot{Q}_{out1L}$ e $\dot{Q}_{out1B}$, in the most general situation. He suggests that the relationships among the areas of the surfaces, so much of gain as of loss of heat, be indicative parameters for those decisions, in a configuration, in the configuration hollow cathode, in conjunction with the reason height / diameter of the hollow cylinder. Later on, a better characterization of the coefficients of heat transfer should be made. Besides results obtained with to present methodology, they were also made analyses and comparisons with SOUZA Jr. data. et al. (2002), that accomplished experimental rehearsals of sintering/heating in copper samples heated up for 900ºC and submitted the polarization volatges: 706V, 744V and 790V, in the configuration of hollow cathode tend as material of the support stainless steel AISI 304 ($k = 14.9\ W/m^2K$, $\rho = 7900\ Kg/m^3$, $C_p = 477\ J/KgK$, $h_1 = 2\times10^{-3}\ m$(height), $\phi = 24\times10^{-3}\ m$(thickness)).

4 - RESULTS AND DISCURSSION

The experimental parameters used by SOUZA Jr. et al. (2002) it is shows in the Tab. 1 to proceed. It should be observed that two values of incident potency of energy on the samples, for each polarization voltage, they are shown in that Tab. 2- 4; where: $k = 6\times10^{-3}\ (W/m^2K)$, $\rho = 8954\ (kg/m^3)$, $C_{p=}\ 383\ (J/kgK)$, $L_1 = 10\times10^{-3}\ (m)$, $\phi = 6\times10^{-3}\ (m)$, $h_1 = 1\ (W/m^2K)$, $h_{L1} = 20\ (W/m^2K)$, $h_2 = 0.1\ (W/m^2K)$, $h_{L2} = 0\ (W/m^2K)$, $h_{B2} = 60\ (W/m^2K)$, $Q_{in\_L1} = Q_{in2T} = 2\times Q_{in1}\ (J/s)$.

The fact of those values is used in the simulations computational, extremely high temperatures would be obtained, not reproducing the experimental data. The values really used in the present work they were obtained starting from the curves of temperatures attribute by the authors, for the employment of the Equation (47), which evaluates the incident potency, Q_{in1T}, in $t=0$..

Table 1. Parameters of entrance of the analyses of SOUZA Jr. et al.

Properties	Value 706 V	Value 744 V	Value 790 V
Q_{in1T} (J/s)	9.8297 (26,2)$^{(1)}$	12.595 (26,3)$^{(1)}$	16.020 (28,0)$^{(1)}$
T_{ini} (K)	370.91	374.98	358.69
A_1 (m^2)	7.853981×10^{-5}	7.853981×10^{-5}	7.853981×10^{-5}

(1) : Original data SOUZA Jr. et al. (2002)

That disagreement perhaps has given by the fact of the initial data temperatures (before *100 ºC)* they be suppressed, for being of data of plasma cleaning, as well as the fact of it not to have waited the exhibition to catch a cold the temperature it sets and starting from there to begin the sintering/heating process properly said. In that way, being followed those procedures, it would be possible to calculate starting from the experimental data the real values of Qi_{n1T} that heated up the sample in the heating process.

The Fig. 2 it illustrates the results obtained for the temperature in the surface of the sample through the simulation, being used the model (2D-t) with proposed support, being still considered the variation of the thermal properties *Cp, K and* ρ in according to Goldsmith et al. (1953), Bisra (1953) and Blodgett(1984) with voltage of 706V.

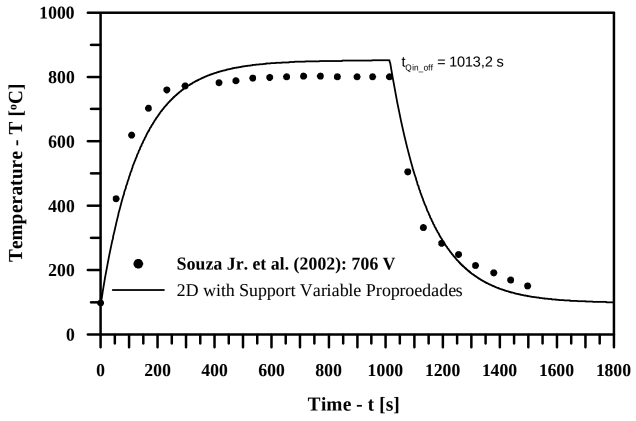

Figure 2. Evolution of the instantaneous medium Temperature in the sample in the heating/cooling process.

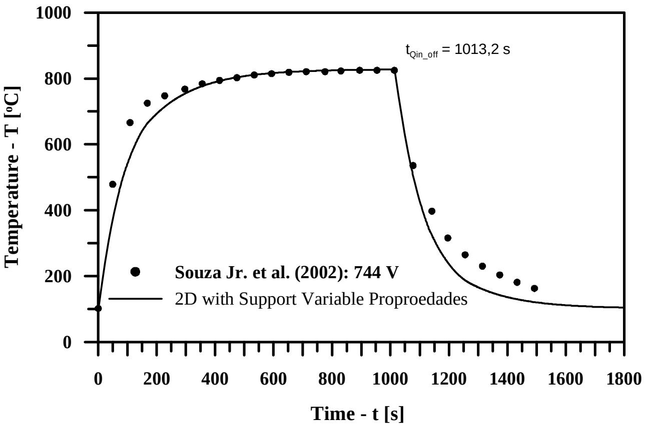

Figure 3. Evolution of the instantaneous medium Temperature in the sample in the heating/cooling process

The behavior of the temperature curves in the Fig. 2 demonstrates that the proposed model possesses good correlation with the experimental data, reproducing the physical phenomenon well in the presence of a support can not it, still, to obtain the temperature difference between the experimental data and the proposed model so much in the heating as in the cooling that is in agreement with the Tab. 2 of approximately *109 ºC* the maximum difference in *t =108s* and minimum difference of *43.61* for *t = 593s* during the heating already in the cooling the maximum difference went of 50.83 in *t = 1013s* (moment in that separated the source) and of *13.63 ºC* the minimum difference in *t = 1196s.*

In that way, it can be inferred of this analysis that the proposed model reproduces in a satisfactory way the heating/cooling process, being attributed to those differences the intrinsic characteristics of the experiment.

The Fig. 3 and 4 illustrate, respectively, the same characteristics of the previous illustration, being considered now the voltages of 744 V in the illustration 3 and 790 V in the Fig. 4 also in according to Goldsmith et al. (1953), Bisra (1953) and Blodgett(1984) , for the entrance parameters that are shown in the Tab. 1.

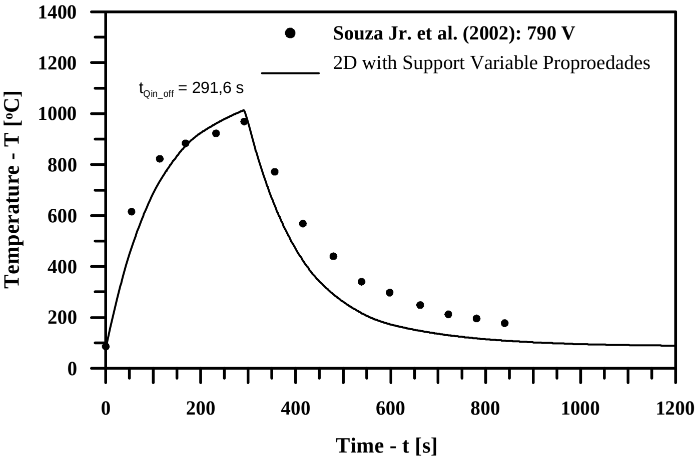

Figure 4. Evolution of the instantaneous medium Temperature in the sample in the heating/cooling process..

In the Fig. 4, the behavior of the temperature curve between the proposed model and the experimental data had good correlation mainly when the regime transient went reaching and in the begin in the cooling. The Tab. 2 illustrates the temperature difference among the two curves.

Table 2. Analysis of the Temperatures for voltage of 706 V: Experimental x Theoretical.

Time (s)	Experimental data (ºC)	Theoretical data (ºC)	Difference of Temperature (ºC)
108	619.14	509.50	109.64
593	798.57	841.98	43.61
1013	800.41	851.26	50.85
1196	*283.10*	*296.,73*	13.63

Thus, inferred that the proposed model, also, it reproduces in a satisfactory way the heating/cooling process, being attributed to the differences the intrinsic characteristics of the experiment.

Table 3. Analysis of the Temperatures for Voltage of 744 V: Experimental X Theoretical

Time (s)	Experimental data (ºC)	Theoretical data (ºC)	Difference of Temperature (ºC)
108,73	665.99	560.16	108.83
593,08	814.66	816.24	1.58
1013	824.85	827.01	2.16
1196	*315.68*	*241.56*	74.12

In way to simulate in the Fig. 4, the behavior of the temperature curve between the proposed model and the experimental data continued with good correlation. Through the Tab. 4 that illustrates the temperature difference among the two curves inferred that the proposed model, also, it reproduces in a satisfactory way the heating/cooling process, being attributed to the differences the intrinsic characteristics of the experiment.

Table 4. Analysis of the Temperatures for Voltage of 790 V: Experimental X Theoretical

Time (s)	Experimental data (ºC)	Theoretical data (ºC)	Difference of Temperature (ºC)
113.67	822.81	731.89	90.92
291.6	969.45	1013.7	44.25
415.16	568.23	424.08	144.15
780.89	195.52	117.73	77.49

For ends of visualization of the thermal field in the samples, so much in the heating, Fig. 8, as in the cooling, Fig. 9, its shows contour map with lines flows of levels of sample and support for voltage of 706 V, for the same experimental conditions described previously in the Tab. 1.

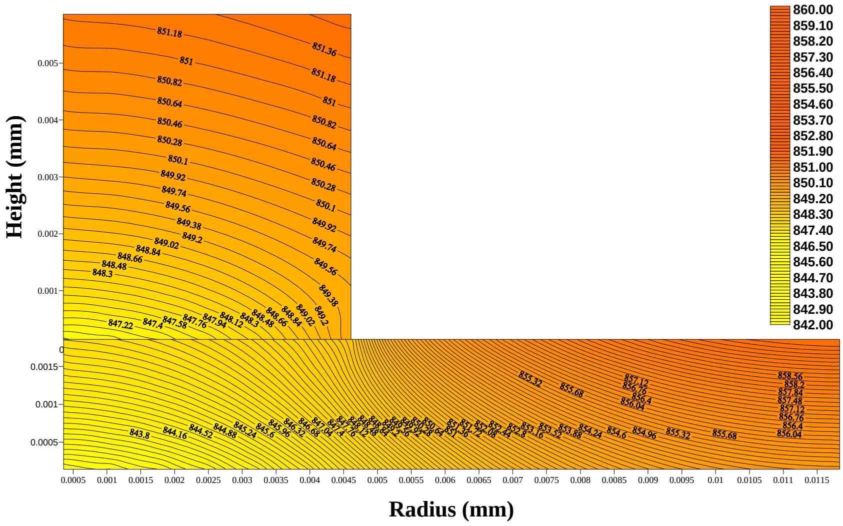

Figure 8. Contour Map with lines of levels and flows for sample during the heating *t=1000s* 706 V.

Analyzing the Fig. 8 and 9 can be inferred that there is thermal gradient in the sample and in the support as much heating as in cooling.

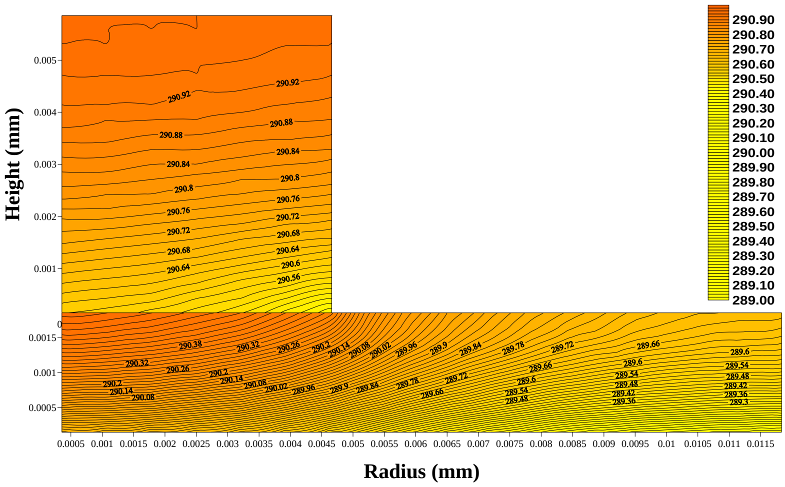

Figure 9. Contour Map with lines of levels and flows for sample during the cooling *t=1200s* 706 V.

5 - CONCLUSIONS

In agreement with the presented results, all the comparisons with the experimental data indicate for the validation of the model computational proposed for the simulation of the process to transfer of heat of solids immerged in plasma. In spite of not taking explicitly to consider the thermal characteristics of the experimental apparatus, procedure to be implemented in the simulations; the obtained temperature information in a global to showed, on one side, to be useful in the process of validation of the codes, and on the other hand, they indicated possible cares when taking place the experiments, because the presence of a support has a great influence in the results.

In general, can to be conclude that Fig. 8 and 9 suggests a good experimental representativeness of the model computational due to the possibility of study of the influence of the support, in the case of the heating process as well affirmed BORBA (2003), but non influence in the process of cooling of a sample,

For example, some inherent characteristics to the process of thermal treatment for plasma, to be heating or cooling, they can be analyzed easily by the developed code. Thus, temperature distribution, temperature levels, thermal gradients inside samples, influence of the thickness, material, width, finally of the dimensions and properties of the samples and supports can be obtained easily starting from the simulations. Still as example, for the analyzed situations, the variation of thermal properties in temperature function influenced significantly in the results, in the situations of those simulations in that the presence of the support was considered. Certainly, that variation, in the thermal conductivity, in the specific mass and in the specific heat, it is shown extremely strong when is considered the capacitance of the support employee's material in the apparatus (Belisio, 2007).

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