TO GATCHINA DISCHARGE NATURE

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Introduction

During last years [1-5] have been created several types of autonomous spherical luminescent objects – plasmoids in experiments with gas discharges in air. In, the so-called, Gatchina discharge, the electric discharge is realized at an energy put between two electrodes, one of which is at the bottom of a vessel, and the second electrode- over a surface of a liquid with which the given vessel is filled. The principle scheme [4] of a circuit for and "plasmoid" generation is represented in Fig.1.

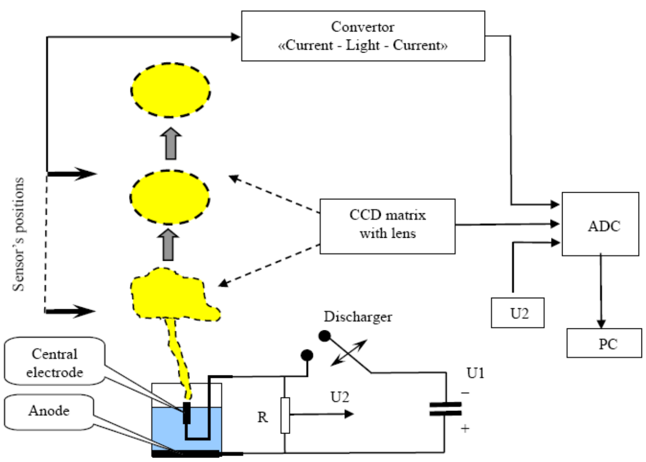


Fig.1. Principle scheme of a circuit for and "plasmoid" generation [4].

During processes of energy put in, its part, in a form of a plasma, is released over the upper electrode, and then over it a luminescent sphere, a plasmoid, [2-5] of radius up to 6 cm appears. These experimental realizations of spherical-like plasmoids authors connected with realization of natural ball lightning analogous due to their characteristics, such as existence with luminescence from milliseconds to shares of seconds, as in [2-5], and 1-2 seconds, as in [1], and comparable sizes with natural BL. However to the contrary majority of ball lightning observations they rose in air and in the end of their lifetime they transformed in rings. It was supposed in [2-3], that these spheres represent cold objects with temperature below 500 °C, however the optical measurements of [4-5] have shown, that the gas temperature in the sphere can reach 1700 °C as a result of the chemical reactions (combustion) which are taking place at a stage of discharge realization. In [1] temperature measurements inside the objects were not made, so this question stays open, though high temperature inside the sphere could lead to its floatation.

In [7] has been made a supposition, that these plasmoids represent some vortical structures developing when the streams were realized in the given experiments. In [8] a confirmation of this assumption has been obtained when a development of a gas stream from the top hot electrode was observed. In the experiments interpretations [2-3] the stream development to a vortex was not considered. In [1] a development of plasmoids was compared with a behavior of smoke rings that also indicates the gasdynamic nature of the object connected with burning processes inside it.

In this situation it is reasonable to carry out preliminary mathematically-computational modeling of gasdynamic processes of similar objects appearance and existence. Therefore, a purpose of these preliminary investigations is formulation of a mathematical approach, allowing to model origination and behavior of objects similar to the experimental plasmoids. However plasma processes during the discharge development and realized on the surface of the spherical plasmoid ensuring its illumination we leave aside until we understand the gasdynamic nature of rising objects and step by step formulate adequate gasdynamic model.

Formulation of a plasmoid mathematical model

The experimental scheme which we consider for modeling is the following, see Fig.1-2. In the centre of a cup in diameter of 20 cm is a tube in diameter of 3-5 mm. From a tube the impulse pushes out a plasma stream of which a luminescent object is formed. Experiments are carried out at atmospheric pressure and room temperature. It is supposed, that the appearing luminescent plasmoid is a toroidal vortex [9]. The current of the plasma is mainly defined by air movement; therefore for numerical modeling of the luminescent plasmoid formation process we will use the classical equations of gas dynamics [10].

We will consider therefore Navier-Stokes equations in a form:

$$\frac{\partial \mathbf{U}}{\partial t}+\frac{\partial \mathbf{A}}{\partial r}+\frac{\partial \mathbf{B}}{\partial z}=\mathbf{C}, \qquad (1a)$$

Where

$$\mathbf{U}=\begin{bmatrix}\rho\\ \rho v_r\\ \rho v_z\\ \rho h\end{bmatrix},\ \mathbf{A}=\begin{bmatrix}\rho v_r\\ p+\rho v_r^2\\ \rho v_r v_z\\ \rho v_r h\end{bmatrix},\ \mathbf{B}=\begin{bmatrix}\rho v_z\\ \rho v_z v_r\\ p+\rho v_z^2\\ \rho v_z h\end{bmatrix},\ C=\begin{bmatrix}-\rho v_r/r\\ -\rho v_r^2/r+\nu\left(\partial^2 v_r/\partial r^2+\partial^2 v_r/\partial z^2\right)\\ -\rho v_r v_z/r+\nu\left(\partial^2 v_z/\partial r^2+\partial^2 v_z/\partial z^2\right)\\ 0\end{bmatrix} \qquad (1b)$$

$$p=\frac{\rho}{\mu}RT. \qquad (1c)$$

Here (v_r, v_z) - components of the of the speed, ν - viscosity, ρ - density, p - pressure, h - enthalpy , $C_P = \text{const}$ - thermal capacity, T - temperature, μ - molar weight of air, R - universal gas constant.

These equations will be solved in the cylindrical area D

$$r\in[0,R_D],\ z\in[0,Z_D]. \qquad (2)$$

On the cylinder boundaries we set the following boundary conditions:

$$\left.\frac{\partial v_r}{\partial r}\right|_{r=R_D}=0,\left.\frac{\partial v_z}{\partial r}\right|_{r=R_D}=0,$$

$$\left.\frac{\partial v_r}{\partial r}\right|_{z=Z_D}=0,\left.\frac{\partial v_z}{\partial r}\right|_{z=Z_D}=0,$$

$$p|_{z=Z_D}=p|_{r=R_D}=p_0. \qquad (3a)$$

and the following conditions on the line of axial symmetry

$$v_r(t,0,z)=0,\ \frac{\partial v_z}{\partial r}(t,0,z)=0,\ \frac{\partial p}{\partial r}(t,0,z)=0,$$

$t \geq 0$.

Boundary conditions corresponding to inflow from the tube are chosen the following:

$$v_r\Big|_{0<r<R_T,z=0}=0$$

$$v_z\Big|_{0<r<R_T,z=0}=v_{\max}\cdot f(t)\cdot g(r) \qquad (3c)$$

$$T\Big|_{0<r<R_T,z=0}=T_{\max}$$

where

$$f(t)=(1-\cos(2\pi t/\Delta t))/2, g(r)=(1+\cos(\pi r/r_0))/2. \qquad (3d)$$

Initial conditions correspond to a motionless air:

$$v_r(0,r,z)=v_z(0,r,z)=0,\ p(0,r,z)=p_0,$$

$$r\in[0,R_D],\ z\in[0,Z_D].$$

We will solve the equations (1) - (4) with the help of the differential schemes [11].

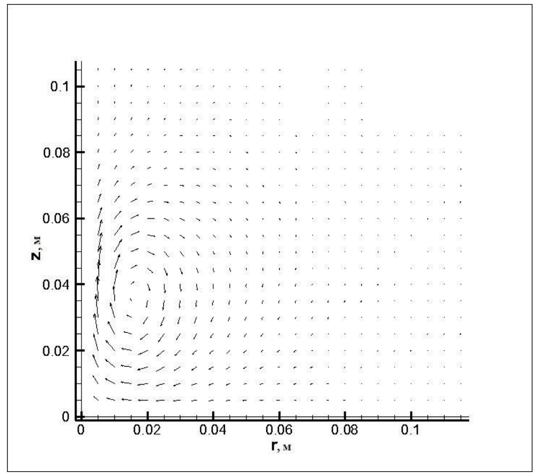
Typical values of parameters are: the radius of the cylinder $R_D \approx 510$ cm, the height of the cylinder $Z_D \approx 1020$ cm, the temperature T ~ 20°C, μ = 28·0.785+32·0.215 g/mol - molar weight of air, p_0=101325 Pa -the atmospheric pressure, the radius of the tube $R_T \approx 2.5$ mm, the height of the tube Z_T ≈ 5-10 mm, the time of the impulse $\Delta t \approx 0.01$ s.

Modeling of the stream from the tube.

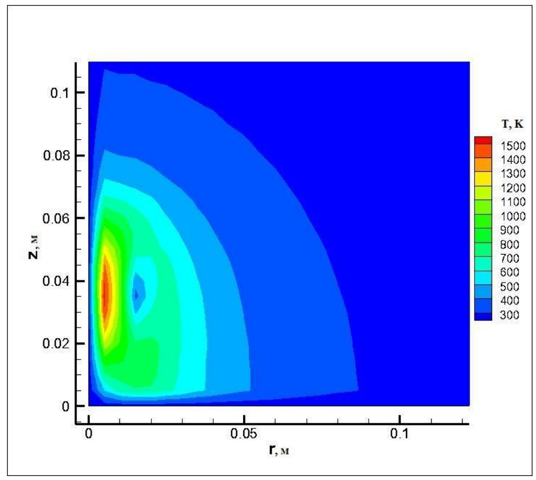
We have carried out mathematical modeling of the experiment at the conditions: the tube radius at inflow - 2.5 mm. The Maximum speed $v_{\max}$ at such values of parameters at the end of the impulse is ~3 m/s, and the maximum temperature $T_{\max} \sim 1500\,K$. The viscosity coefficient values were taken from [12].

In Fig. 1 -2 (a)(b) one can see the speed field of air and temperature distribution at time moments 0.005 s and 0.07 s in the formed toroidal vortex. It can be seen from the drawing that all the calculated area was captured by the motion, at that the vortex speed of ascending is greater than 30 cm/s.

One can see from Fig. 1-2 that the effective diameter of the vortex increases with time, and temperature changes insignificantly at this time interval. The vortex development dynamics shows that it will dissipate in a short time period, what is in qualitative agreement with the experimental time of the vortex existence



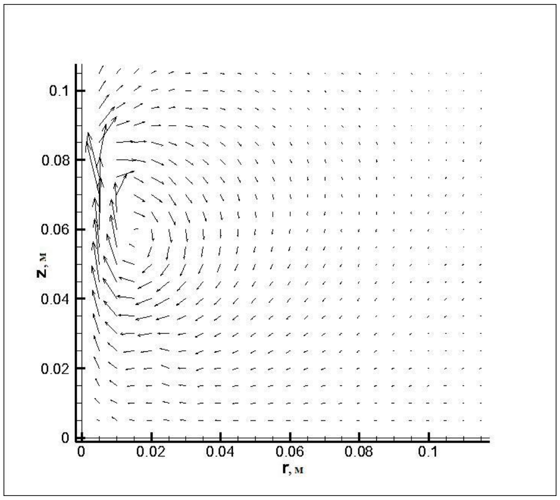
1a)



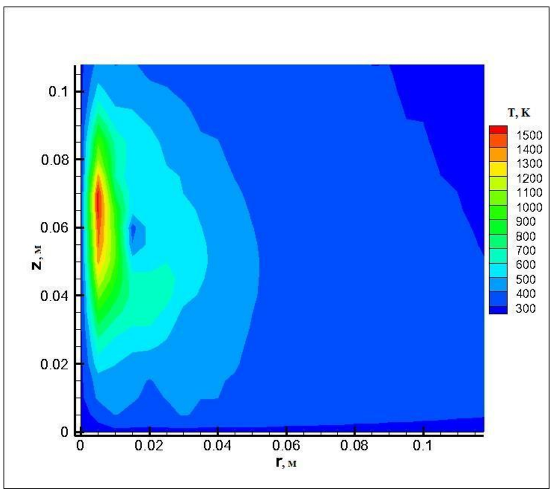
1b)

Fig.1. a) Velocity field in the formed toroidal vortex, t=0.005 s.

b) Temperature distribution in the formed toroidal vortex, t=0.005s.



2a)



2b)

Fig.2. a) Velocity field in formed toroidal vortex, t=0.07s.

b) Temperature distribution in formed toroidal vortex, t=0.07 s.

Conclusions

Our calculation shows that in case of the rising stream from the electrode representing a tube one can observe creation of the vortex. Comparison of the numerical and the physical experiments results allows to conclude a sufficient adequacy of the carried out mathematical modeling of the experiment. Some difference in the sizes of the vortex, generated in the numerical experiment, and the sizes of the luminescent plasmoid in the physical experiment speaks first of all about different moments of time at which the comparison could be made. In the numerical experiment it corresponds to the time moment of the computation after the stream leaking out, and in the physical - to the photo fixing moment of the luminescent spheroid when it reaches the maximal size. The increase in time of the numerical calculation in future will allow us to define the photographing moment of time. However, it is absolutely clear, that the numerical modeling allows find such moments of the physical process of plasmoids creation and existence which were not known earlier from the experimenters. As an example of it can serve the detection of the toroidal vortex which was born in the tube. Thus, the researches carried out in the work have shown that the mathematical modeling in this case is the effective tool of research of physical experiment. We plan to extend our model taking into consideration a realistic form of heated electrode.

The question of the spheroid luminescence requires development of some combustion model of the erosive particles (from the electrode) in air with addition of water vapor, it will be considered later.

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