On modeling of “plasmoid” created by electric discharge

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Abstract. Gas dynamic modeling approach was applied to “plasmoid” formed in experimental electrical discharge breakdown in a cathode ceramic tube filled by a conductive liquid. Measured parameters were applied to the model in order to improve it. Qualitative agreement observed between behavior of the experimental “plasmoid” and model results. Temperature distribution results also agree with experiment in which temperature of 2000 K was registered.

1. Introduction

Numerous experiments performed in recent years [1-4] have led to observations of autonomous luminescent objects (so-called “plasmoids”) being formed in electrical discharge breakdown in conductive liquid. The current article research work is devoted to modeling of the new experiment. Principle scheme of the experimental setup is shown in Fig. 1.

Electric discharge between two electrodes generates approximately 11.67 kJ of energy (see Fig. 2 for measured electric current and voltage). In described setup one electrode is placed on the bottom of a vessel filled with conductive liquid (water + NaBr with the conductivity of 3 mS) while the second electrode is placed over the liquid surface. Resulting generated energy is distributed between molecular excitation of the liquid thus forming active molecules and vapor – and formation of luminescent layer of plasma on the liquid surface around the electrode.
Figure 1. Scheme of the experimental setup for the “plasmoid” generation.
Central electrode - with the ceramic tube.

Figure 2. Evolution of voltage and electric current between electrodes.

Detailed examination of photos of discharge processes show that net-like glowing sparks connecting the liquid surface of the vessel with the liquid surface of the cathode appears. All the liquid in the ceramic tube is blown up to the upper region adjacent to the cathode transforming into the “foam” like mix of water bubbles and vapor. Jet formation emitting a plasma along its axis is observed afterwards. Then the formation reaches shape of somewhat like a glowing sphere which finally evolves into a vortex toroid.

In Fig.3 one can see evolution in time of our “plasmoid”, and in Fig.4 schematics of experimental media motion is presented.

“Gatchina” discharge experiments [2] reveal complicated chemical processes inside the “plasmoid” resulting in temperature rise up to 2000 K. Explanation was given to long life of plasmoids by Egorov...
and Stepanov in [3] based on formation of stable clusters consisting of two hydrated ions of opposite signs and water molecules preventing hydrate ions recombination and this extending the life-time of ions existence. In reference [4], published after our [5] was shown that the plasmoid is transformed in the ring during evolution. This corresponds to results of gas-dynamic calculations [5-6]. In them was proposed that such objects have a structure of toroidal vortexes formed by a jet pulse which are known to be stable and long-lived [1].

![Figure 3. Experimental evolution of the “plasmoid”](image-url)
2. Mathematical model
Presented model is based on the model previously used by authors [5-6] which is based on unsteady viscous gas dynamic approach. Partial differential equations (1) – (3) were solved using Finite Volume Method [7].

Generated heat was applied as a source in region around central electrode; mass inflow was applied at ceramic tube circular surface area so that total gas media mass would be the same as the mass of water contained in the tube.

We will consider therefore Navier-Stokes equations with respect to axis-symmetry in a form:

$$
\frac{AU}{\partial \rho} + \frac{A}{\partial \rho v_r} + \frac{B}{\partial \rho v_z} + \frac{C}{\partial \rho h} = 0,
$$

where

$$
\begin{bmatrix}
\rho \\
\rho v_r \\
\rho v_z \\
\rho h \\
\end{bmatrix} A =
\begin{bmatrix}
\rho v_z \\
p + \rho v_z^2 \\
\rho v_z v_r \\
\rho v_z h \\
\end{bmatrix} B = 
\begin{bmatrix}
-\rho v_z / r \\
-\rho v_z^2 / r + v \left( \partial^2 v_z / \partial r^2 + \partial^2 v_z / \partial z^2 \right) \\
-\rho v_z v_r / r + v \left( \partial^2 v_z / \partial r^2 + \partial^2 v_z / \partial z^2 \right) \\
0 \\
\end{bmatrix} C;
$$

$$
p = \frac{\rho}{\mu} RT.
$$

Here \((v_r, v_z)\) - velocity components, \(V\) - viscosity, \(\rho\) - density, \(p\) - pressure, \(h\) - enthalpy. These equations will be solved in the cylindrical area 50 cm in radius and 100 cm in height, inlet radius of 5 mm corresponds to ceramic pipe surface radius.

Duration of the «jet impulse» \(\Delta t\) was set to 110 ms according to experimental measures. Boundary conditions are described in the Fig. 5.

Unsteady heat generation was set as:

$$
q_v = \begin{cases} 
1.167 \cdot 10^4 \frac{W}{\Delta t}, & 0 \leq t \leq \Delta t \\
0, & t > \Delta t
\end{cases}
$$

Formation of gas media out of water in ceramic pipe was set as mass flow:

![Figure 4. Experimental schematics of media motion.](image)
\[ m = \begin{cases} 3.14 \times 10^{-4} \text{ kg}, & 0 \leq t \leq \Delta t \\ 0, & t > \Delta t \end{cases} \]

Figure 5. Task definition: а – boundaries, б – boundary condition. Initial conditions correspond to still air at standard conditions.

3. Simulation results

Our modeling results at different moments of time are presented in Fig. 6-7. The fact that formation of heated volume can be seen with vortex structure in its upper part (Fig. 7) agrees with conclusions in work [5] – also vortex diameter is very close to the one observed in the experiment. Vortex toroid structure lifetime is estimated about 0.25 s which is close to measured times of this experiment and [2]. One must admit the remaining hot “leg” in the bottom – which brings us to conclusion that discharge heating in the whole conducting gas volume should be considered in further investigations.
4. Conclusions

Results of modeling of discharge “plasmoids” observed in presented experiment were presented in the current paper. Numerical experiments were carried out for proposed model of gas heated around the central electrode.

Simulation results even under carried out simplifications are in agreement with “plasmoid” dynamic observed in the experiment. Temperature distribution also agrees with experiment [2] in which temperature of 2000 K was measured.
Existing disagreement brings us to conclusion that the model should be updated with more complicated heat release in the whole volume of the “plasmoid” with respect to plasma radiation effects.

References

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