Physical effects in electrical discharge of atmospheric pressure caused by external flow of copper cathode by water

Kh K Tazmeev¹, B A Timerkaev² and G Kh Tazmeev²

¹Kazan Federal University Naberezhnye Chelny Institute, 68/19 Mira Street, Naberezhnye Chelny, 423810, Russian Federation
²Kazan National Research Technical University named after A.N. Tupolev, 10 K. Marx str., Kazan, 420111, Russian Federation

E-mail: tazmeevh@mail.ru

Abstract. This article experimentally studies gas discharge between copper electrodes in the current range of 5-20 A. The electrode spacing was varied in the range of 45-70 mm. The cathode was a rod with a diameter of 10 mm and was located in the water stream, poured from a dielectric tube. Three variants that differed in the working end of the cathode arrangement were studied: 1) over the water; 2) on the surface of the water; 3) underwater. It was established that in the second variant in the plasma column near the cathode an extended area is formed with intense radiation of hydrogens. In the third option, a significant erosion of the cathode was detected. It was revealed that in the process of erosion fine particles of copper metal are formed.

1. Introduction

In recent years there has been a significant increase of interest to the gas discharge excited in the presence of a water medium. We study different types of gas discharges: high-voltage, low-voltage, pulse wise and others. Some research is directed to the use of gas discharges for the synthesis of nanoparticles underwater and in aqueous solutions. In review articles dozens of ways to implement this process are listed [1-3].

The aim of this work is the experimental study of gas discharge of constant current in the air flow under condition of the external flow of metal cathode by water. More often, a solid state cathode is completely immersed in the water flow. This type of cathode arrangement is found in many studies [4-14]. In cases where a metal cathode extends from the water flow or is close to this state, the gas discharge isn't studied enough. Research in this work is aimed to study these variants.

2. Experiment

Gas discharge was ignited in the air between copper electrodes at currents of 5-15 A. The power supply was rectifier with smoothing filter. The output voltage was of 1760 V. The current was limited by ballast resistor. Discharge was oriented in the vertical direction. The cathode was located at the bottom and the anode - at the top. The anode was a water-cooled disk with a diameter of 50 mm. It was placed horizontally. The cathode was made as a rod with a rounded end and was mounted within a dielectric tube (figure 1). Water was fed into the gap between the metallic cathode and the internal wall of the tube. Distilled water was used to prevent scale formation in the cooling system. Its specific
electric conductivity was in the range of 100 to 600 μSm/sm. These slightly higher values were obtained because of the content of sodium chloride in the units and aggregates of the cooling system.

Figure 1. Cathode assembly. 1 – copper bar; 2 – dielectric tube. d – 10 mm; D – 12.7. The arrows indicate the direction of water flow.

Voltage \( U \) and current \( I \) were recorded by digital storage oscilloscope AKIP-15/1, with guidance band of 25 MHz. Photographing and spectroscopy of a gas discharge were carried out with speed camera Videoscan-415 and high-speed fiber-optic spectrometer AvaSpec-3648. Camcorder let receive frames with an exposure of up to 1 μs. Spectrometer recorded radiation in the wavelength of range 484-708 nm with a resolution of 0.15 nm (diffraction grating 1200 lines / mm, the input optical gap is 10 microns). The radiation of the individual sections of the discharge area was projected on the entrance of the spectrometer through an assembly, combined of collecting lens and the optical gap.

Experiments were performed at various projections \( h \) of copper rod cathode. Three options have been identified. A characteristic feature, distinguishing these options from each other, was the end location of the upper edge of the cathode relative to the water level in the insulating tube (figure 2).

Figure 2. Instant photos of gas discharge at different variants of cathode water flow. Exposure 200 μs. The end of the metal cathode: (a) – above the water \( h = 5 \) mm; (b) – on the surface of water; (c) – underwater on the depth of 0.5 mm. Water consumption: (a) top row – 10 r/c; (a) lower row, (b), (c) – 1.5. Average current: (a) top row – 10.0 A; (a) lower row, (b) – 14.7; (c) – 8.7. Anode-to-cathode distance: (a) – 45 mm; (b), (c) – 50 mm.

In option (a) at low flow of water there was a narrowing of the discharge channel near the cathode (figure 2(a), lower row). On instant photos this discharge portion manifested in a scarlet color, which is relevant to the Balmer line \( \text{H}_\alpha \) in spectrum of the hydrogen emission.

Having switched to option (b) picture near the cathode slightly changed. Bright narrow channel near the cathode lengthened and stretched vertically (figure 2(b)). The yellow background formed around it.
A characteristic feature in option c was that the discharge channel was colored green lengthwise. This color indicates the intensive introduction of copper atoms in the discharge region. Apparently, copper atomic is formed in the cathode electrolysis processes.

![Radiation spectrum of a gas discharge (option b). Distance from the cathode – 30 mm. Anode-to-cathode distance – 50 mm. Optical gap width 0.50 mm. Water consumption – 1.5 g/s. Current – 10.0 A.](image)

The presence of hydrogen, sodium and copper in a gas discharge plasma column confirmed spectral studies (figure 3). Distributions of emitting atoms along the discharge channel, received from research results, to comply fully with the images on the instant photography.

In options (a) and (b) discharge burned steadily. Its electrical parameters were stable and remained virtually unchanged over time (figure 4).

![Oscillograms of gas discharge at different options of cathode water flow. Water consumption – 1.5 g/s. Electric conductivity – 370 µSm/sm. Anode-to-cathode distance – 50 mm.](image)

In the option (c), i.e. when copper cathode was underwater, there was a significant erosion of its end. Some results of these processes are shown in table. In the experiments specific electric conductivity of water was within 200 - 225 µSm/sm. The water flow was 1.5 g/s.

Specific erosion $\gamma$ of copper cathode was enough large quantity. It is noteworthy that the numerical value of its order of magnitude is the same as a in a vacuum pulse discharge at multiple inclusions of current [15].
Table 1. Specific erosion of copper cathode.

| <I>, A | γ, μg/Kl | <I>, A | γ, μg/Kl |
|-------|----------|-------|----------|
| 9     | 22.3     | 15    | 21.6     |
| 12    | 20.6     | 18    | 19.1     |

In the products of erosion under the microscope in reflected light are clearly visible particles of metallic copper, which also indicates of the probability of micro-explosions' origin. Technical capabilities of the microscope allowed observing particles with sizes of tens of micrometers. It is possible that smaller size particles exist.

3. Conclusions
Water flow around a copper cathode, causes significant changes of the gas discharge properties. These changes are most clearly manifested in two options of finding a copper cathode in the aqueous stream. These options differ in the working end of the cathode: on the surface of water and underwater. In the option, when the cathode end face is on the surface of water in the plasma column near the cathode is formed zone where hydrogen atoms radiation prevails. It can be assumed that under the influence of the gas discharge formed a stream of steam-plasma directed from the surface of the water vertically up.

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