Investigation of periodic discharge in liquid flow

D. Sinelnikov, D. Bulgadaryan and G. Buyanov

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe shosse 31, 115409 Moscow, Russia

Abstract. Periodic discharge in water flow was investigated using optic spectrometer and 1000 fps video camera with the discharge pulse up to several milliseconds long regulated by water flow speed. Copper drops were found on the cathode surface in the case of copper-tube anode. In spite of water cooling anode can reach melting point. Optic spectra were compared for several materials of electrodes. For copper electrodes it was found that anode is the main contributor of copper in discharge plasma.

1. Introduction
Impulse discharge in a liquid flow at atmospheric pressure can significantly modify the surface of the electrodes, changing both the morphology of the surface and its mechanical characteristics[1]. Cooling of the sample with a liquid during discharge does not allow it to be overheated up to temperatures close to melting point, while the power deposited from the discharge can be as high as several kW per several cm² area of a treated surface.

2. Experimental setup and samples
In figure 1 one can see experimental setup scheme. Water is supplied from the reservoir 1 through the tubular anode 2, so that a discharge gap of 0.5-1 cm long it passes in a drip mode with a droplet drop frequency of several Hz. The voltage up to 7 kV is applied to the anode using BP-138 power supply. When a drop of water during the fall commutates the discharge gap, a breakdown occurs leading to the sprinkling of water. After the end of the breakdown pulse the capacitor 5 with a capacity of 0.5 µF at 20 kV starts recharging until the next triggering by water drop.
Since there is a lot of noise in the discharge circuit preventing the measurement of frequency, current, discharge voltage and other electrical parameters, we focused on spectroscopic measurements of the discharge plasma composition. Four samples and two tubes with different materials were used to investigate how electrode materials influence on discharge plasma. Sample materials were copper, aluminum, titanium and graphite, and tube materials were copper and stainless steel.
Figure 1. Experimental setup scheme: 1 - reservoir with water, 2 - tubular electrode (anode), 3 - processed sample (cathode), 4 - power supply unit BP-138, 5 - capacitor

3. Energy-dispersive X-ray spectroscopy analysis of the samples

Scanning electron microscopy with energy-dispersive X-ray spectroscopy (EDS) was used to check material transfer from one electrode to another during the discharge. In the case of copper tubular anode on the surface of all cathodes (with the exception of the copper one, where it cannot be distinguishable) small copper balls were found with ~10 μm diameter shown in figure 2. That means that anode temperature reaches the melting point even for short discharge pulse period.

Figure 2. Copper drop on the aluminum sample surface after the discharge

4. Discharge dynamics

For investigation of the discharge dynamics 1000 fps camera was used. Only in some cases one can find by analyzing the video 3-5 frames, where discharge shining cloud dimensions increase or decrease slightly changing its shape. This means that the discharge duration can be up to several ms long. Taking into account 1A current of power supply it can charge 0.5 μF, 20 kV capacitor for 1 ms, but if the time between two pulses is shorter, than maximum discharge voltage is lower than 6 kV. However, it cannot be lower than several hundred volts, minimum voltage sufficient for providing conductive channel in water vapor in 1 cm gap [2]. That could mean that shortest pulses should be several tens of microsecond duration.

5. Optical spectroscopy of the discharge

Optical spectroscopy of the plasma was made using AvaSpec 2048x14 spectrometer, and typical spectrum is shown in fig. 3. Maximum intensity in it was for hydrogen (H\textsubscript{α} 656 nm and H\textsubscript{β} 486 nm lines) and atomic oxygen due to water molecules decomposition. Since discharge was in the air, the products of nitrogen molecules decomposition are also presented. One can also see copper lines in the left part of the spectrum due to electrode erosion.
Experiment was made for several pairs of electrode materials and measured spectra are shown in fig. 4. The right parts of the spectra were the same for all electrodes while the left parts were different.

Two spectra with maximum intensity were measured for titanium cathode and the most intense lines correspond to atomic and ionized titanium. The spectra for graphite cathode have minimum intensity and comparing spectra with stainless steel and copper anode one can see the deposition of the anode material in the spectrum. Comparing copper-copper and copper-stainless steel spectra one can see that copper intensity is similar in them that could be because of the cooper anode was the main contributor of copper in plasma.
6. Conclusion
Periodic discharge in liquid flow was investigated using optical spectroscopy. Maximum intensity was for hydrogen (H\(_\alpha\) 656nm and H\(_\beta\) 486nm lines) and atomic oxygen due to water molecules decomposition. Comparing copper-copper and copper-stainless steel spectra copper anode was the main contributor of copper in plasma. It was shown that discharge pulse can be up to several milliseconds long, but more often shorter and can be varied from several tens of microseconds. EDS analysis of the cathodes demonstrates copper drops in the case of usage of copper anode, meaning that anode temperature reaches melting point even for short discharge pulse period.

References
[1] Bogdanovich, B.Yu., Nesterovich, A.V. Analysis of main regularities of periodic discharge passing in fluid stream (2016) J. of Phys.: Conf. Ser., 747 (1), статья №012001.
[2] N. Škoro, D. Marić, G. Malović, W. G. Graham, and Z. Lj. Petrović Electrical Breakdown in Water Vapor (2011) Phys. Rev. E 84, 055401(R).

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