PLASMA-LIQUID SYSTEM WITH REVERSE VORTEX FLOW OF "TORNADO" TYPE (TORNADO-LE)

O.A. Nedybaliuk, V.Ya. Chernyak, S.V. Olszewski

Taras Shevchenko National University of Kyiv, Faculty of Radio Physics, Department of Physical Electronics, Kiev, Ukraine
E-mail: oanedybaliuk@gmail.com

The results of experimental investigations of the plasma in plasma-liquid system with reverse vortex flow of "tornado" type are presented. Volt-ampere characteristic of discharge in the current range from 200 to 400 mA were measured. Emission spectra of plasma in range from 200 to 1100 nm were measured. Excitation temperatures (electronic T_e^*, vibrational T_v^* and rotational T_r^*) were obtained. Emission spectra of hydroxyl OH were calculated.
PACS: 52.50.Dg

1. INTRODUCTION

Today, hydrogen is considered as one of the most perspective energy sources for the future that can be renewable, ecologically clean and environmentally safe [1]. There are various electric-discharge techniques of plasma conversion of the liquid fuel into H_2 using thermal (equilibrium) and nonthermal (nonequilibrium) plasmas: arc, corona, spark, MW, RF, DBD, etc. Among them, one of the most efficient is the plasma processing in the dynamic plasma-liquid systems (PLS) using the DC discharge in a reverse vortex gas flow of "tornado" type [2] with a "liquid" electrode (TORNADO-LE) [3]. The highly developed plasma-liquid interface with the large surface-to-volume ratio and the deep injection of plasma particles into the liquid also favor to the intensification of the liquid fuel conversion in the system. Development and investigation of plasma liquid-system is very perspective and interesting work.

In this paper we report new results of our experimental studies of the plasma parameters in the PLS with the DC TORNADO-LE using available methods of diagnostics.

2. EXPERIMENTAL SET-UP

PLS reactor was prepared with the DC discharge in a reverse vortex gas flow of "tornado" type with a "liquid" electrode. It consists of a cylindrical quartz vessel (1) by diameter of 9 cm and height of 5 cm, sealed by the flanges at the top (2) and at the bottom (3), Fig. 1.

The vessel was filled by the work liquid (4) through the inlet pipe (5) and the level of liquid was controlled by the spray pump. The basic cylindrical T-shaped stainless steel water-cooled electrode (6) on the lower flange (3) made from stainless steel is fully immersed in the liquid. The electrode on the upper flange (2) made from duralumin had a special copper hub (11) with the axial nozzle (7) by diameter 2 mm and length of 6 mm. The gas was injected into the vessel through the orifice (8) in the upper flange (2) tangentially to the cylinder wall (l) and created a reverse vortex flow of "tornado" type, so the rotating gas (9) went down to the liquid surface and moved to the central axis where flowed out through the nozzle (7) in the form of jet (10) into the quartz chamber (12). Since the area of minimal static pressure above the liquid surface during the vortex gas flow is located near the central axis, it creates the column of liquid at the gas-liquid interface in the form of the cone with the height of ~1 cm above the liquid surface (without electric discharge).

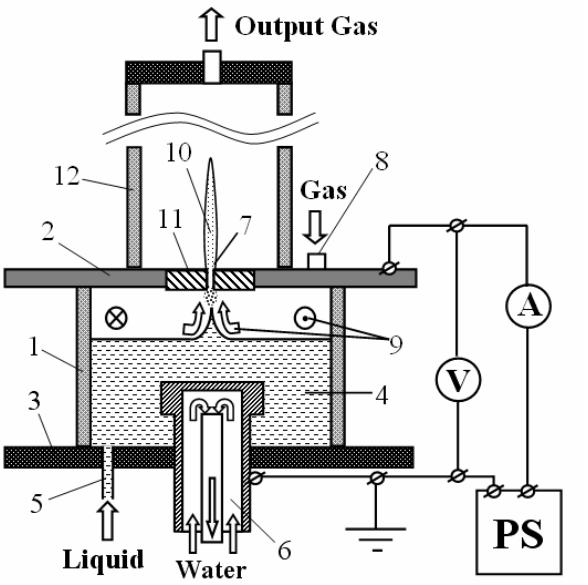

Fig. 1. Scheme of the PLS reactor with the DC discharge in a reverse vortex gas flow of "tornado" type with a "liquid" electrode

The voltage was supplied between the upper electrode (2) and the lower electrode (6) in the liquid with the help of the DC power source powered up to 10 kV. Two modes of the discharge operation were studied: the mode with "liquid" cathode (LC) and the mode with "solid" cathode (SC): "+" is on the flange (2) in the LC mode, and "-" is on the flange (2) in the SC mode. The conditions of breakdown in the discharge chamber were regulated by three parameters: by the level of the work liquid; by the gas flow rate *G*; and by the value of voltage *U*. The pressure in the discharge chamber during the discharge operation was ~1.2 atm, the static pressure outside the reactor was ~1 atm. Plasma torch (10) was formed during the discharge burning in the camera.

Diagnostics of the plasma was conducted by means of optical emission spectroscopy. A high-speed CCD-based spectrometer "Plasma-spec" with a spectral resolution

~0.6 nm was used for the spectra registration in the range of wavelengths 200…1100 nm.

The characteristic temperatures corresponding to excited states of atoms (electronic temperature T_e^*), and molecules (vibrational T_v^* and rotational T_r^* temperatures) in discharge plasma were determined by different methods. To determine vibrational T_v^* and rotational T_r^* temperatures an original technique with using the SPECAIR was used [4, 5].

3. RESULTS

Current-voltage characteristics of the TORNADO-LE in the mode "solid" cathode working in water at different airflow rates are shown in Fig. 2. The discharge in plasma-liquid system is a glowing type.

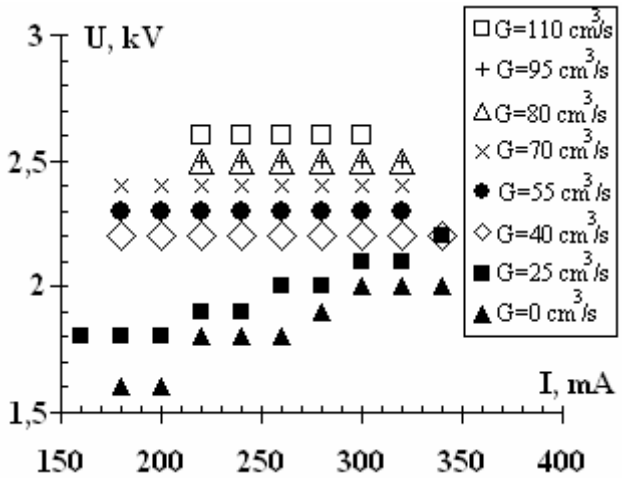

Fig. 2. Current-voltage characteristics of the TORNADO-LE working in water at different airflow rates

Typical emission spectra of plasma in TORNADO-LE inside and outside of reactor are shown in Fig. 3. All this spectra were normalize on maximum at wavelength λ_n=306,7 nm. Hydroxyl OH and nitrogen N_2 Bands, hydrogen H_α (656.3 nm), H_β (486.1 nm), copper Cu and oxygen multiplet O (777.2; 844.6; 926.6 nm) lines are on emission spectra. Nitrogen band N_2(C-B) and copper lines Cu was presented only outside of system.

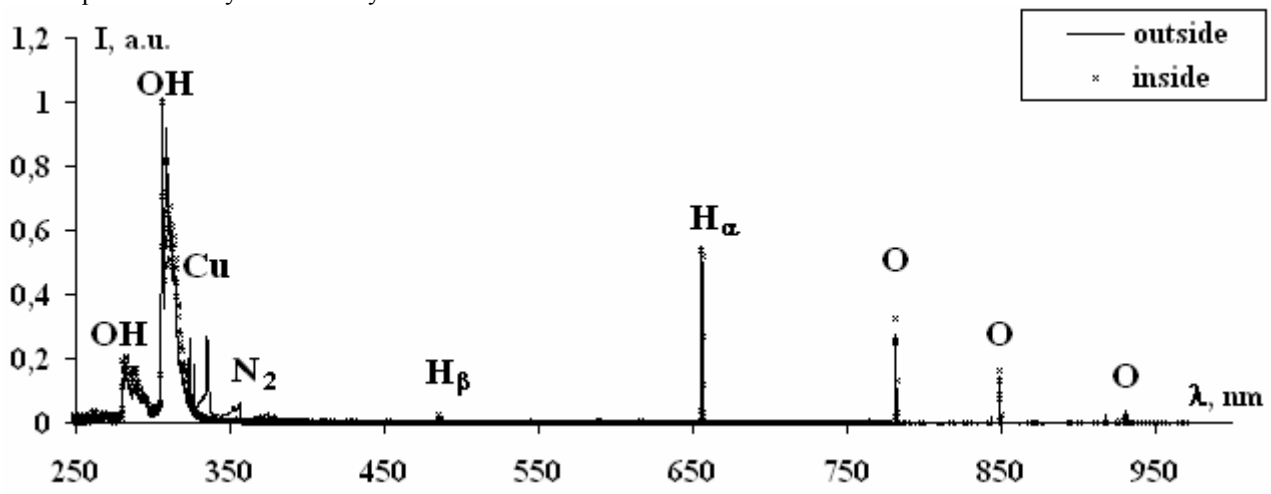

Fig. 3. Typical emission spectrum of discharge plasma inside and outside of reactor in the TORNADO-LE: I=300 mA; G=55 cm^3/s; U=2,3 kV; working liquid – distilled water; gas flow – air; mode with SC

Emission spectra in PLS TORNADO-LE working on distilled water measured at different discharge currents are shown in Fig. 4.

The electronic temperature T_e^* was determined by relative intensities of hydrogen emission lines H_α (656.3 nm), H_β (486.1 nm), relative intensities of emission of oxygen multiplet lines (777.2; 844.6; 926.6 nm)

Excitation temperatures for regime I = 300 mA, G=55 cm^3/s, U=2,3 kV in the mode SC were measured. Excitation temperatures inside of reactor was T_r^*=4000±500 K, T_v^*=4000±500 K and T_e^*= 5000±500 K. Plasma temperatures outside of reactor was T_r^*=4500±500 K, T_v^*=3000±500 K and T_e^*=5000±500 K. Excitation temperatures vibrational T_v^* and rotational T_r^* was obtained by band of OH. Plasma in PLS TORNADO-LE inside of reactor was isothermal. But outside of reactor plasma was nonisothermal.

Experimental and calculated emission spectra by the SPECAIR are shown in Fig. 5.

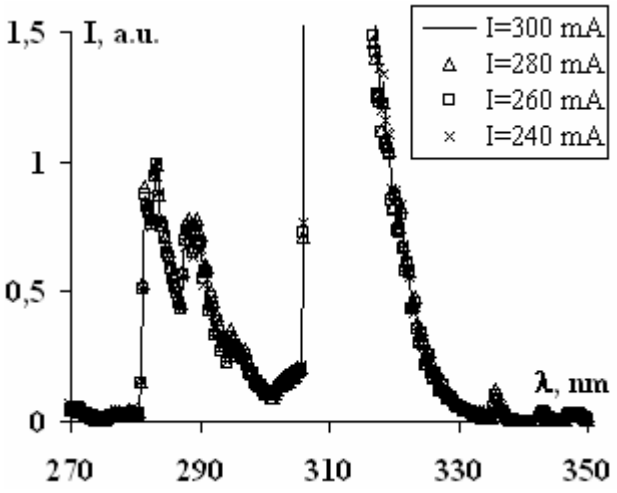

Fig. 4. Emission spectra of discharge plasma in the TORNADO-LE inside of reactor at different discharge currents: working liquid – distilled water; mode with SC; air flow G=55 cm^3/s

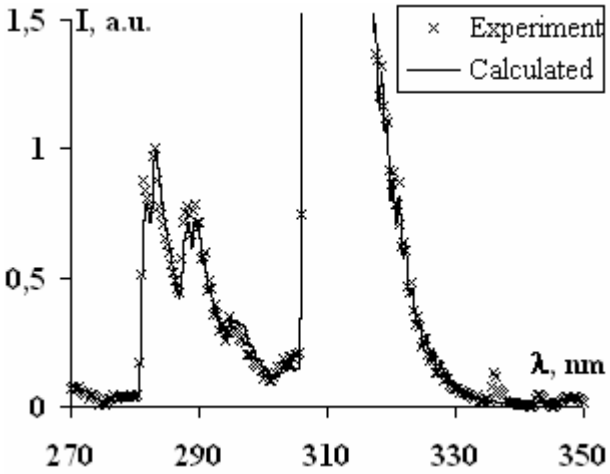

Fig. 5. Experimental emission spectrum of discharge plasma inside of system in the TORNADO-LE and calculated emission spectra by the SPECAIR

4. CONCLUSIONS

The basic components on emission spectra of plasma in TORNADO-LE inside of main chamber are the hydroxyl OH bands, hydrogen H and oxygen O lines.

Two type of plasma attended in PLS TORNADO-LE, isothermal – inside and nonisothermal (decay plasma) – outside of main chamber.

Nitrogen bands N_2 and copper lines Cu were only outside of reactor.

ACNOWLEDGEMENTS

This work was partially supported by the STCU Grant P-354 (EOARD 0880001), Taras Shevchenko National University of Kyiv, National Academy of sciences of Ukraine, Ministry of Education and Science of Ukraine.

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Article received 11.10.10

ПЛАЗМЕННО-ЖИДКОСТНАЯ СИСТЕМА С ОБРАТНО- ВИХРЕВЫМ ПОТОКОМ ТИПА “ТОРНАДО” (TORNADO-LE)

О.А. Недыбалюк, В.Я. Черняк, С.В. Ольшевский

Представлены результаты экспериментальных исследований плазмы в плазменно-жидкостной системе с обратно- вихревым потоком типа “торнадо”. Измерены вольтамперные характеристики разряда в диапазоне токов от 0 до 400 мА. Получены эмиссионные спектры плазмы в диапазоне от 200 до 1100 нм. Посчитаны температуры возбуждения (электронная T_e^*, колебательная T_v^* и вращательная T_r^*). Были рассчитаны эмиссионные спектры гидроксила ОН.

ПЛАЗМОВО-РІДИННА СИСТЕМА ІЗ ЗВОРОТНО - ВИХРОВИМ ПОТОКОМ ТИПУ “ТОРНАДО” (TORNADO-LE)

О.А. Недибалюк, В.Я. Черняк, С.В. Ольшевський

Представлено результати експериментальних досліджень плазми в плазмово-рідинній системі із зворотно-вихровим потоком типу “торнадо”. Виміряні вольт-амперні характеристики розряду в діапазоні струмів від 0 до 400 мА. Отримані емісійні спектри плазми в діапазоні від 200 до 1100 нм. Обраховані температури збудження (електронна T_e^*, коливальна T_v^* і обертальна T_r^*). Були розраховані емісійні спектри гідроксилу ОН.