THE PROPERTIES OF PLASMA-LIQUID SYSTEM WITH ONE LIQUID ELECTRODE

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The results of investigations are presented for a rotational gliding arc with liquid electrode. Emission spectra of rotational gliding arc discharge with liquid electrode were investigated. The discharge voltage as a function of airflow rate were measured. Electronic T_e^*, vibrational T_v^* and rotational T_r^* temperature were determined. Distribution of temperature along the plasma torch was studied.

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INTRODUCTION

There are three main problems in present plasma chemistry, that are related to selectivity of plasma transformation of substances, energy efficiency of plasma technology and the consumption of metallic electrodes material. The problem of selectivity consists in the fact that during the plasma-chemical transformation of substances occur large numbers of chemical reactions. While it is necessary that the reaction occurred that are responsible for the formation of the expected product. This problem is partially solved by using non-equilibrium plasma. Low-temperature plasma is divided onto two types by the level of non-equilibrium: plasma with a temperature of heavy components on the order of room temperature (dielectric barrier discharge, micro-discharge) and the so-called "warm" plasma with a temperature more than 1000 K.

When non-equilibrium "warm" plasma is used, the support of the reforming and combustion of hydrocarbon fuels process will be better, since the process of reforming requires not only the presence of radicals, but also the appropriate temperature. Moreover, the usage of plasma at atmospheric pressure or above it needs for best results.

The problem of energy efficiency of plasma technologies connected with the fact that plasma generation is supported by most expensive energy - electricity. Therefore, a possible way to solve this problem can be embedding of plasma technologies into the traditional chemical technologies. Plasma has been effectively injected into the reaction chamber. Chemical processes must be managed with help of plasma, which it plays a catalyst role.

Atmospheric pressure plasmas can be created by various types of discharges: transverse arc; discharge in gas channel with liquid wall and others. But most of them aren’t sufficiently stable. Stabilization of high pressure discharge in powerful plasmatron is attained by vortex flow of gas [1]. In the low-powered high pressure discharges the reverse vortex flow “tornado” type can be used for the space stabilization [2]. Previous investigations were performed only for discharges with solid-state electrodes. And we have not much information about discharges with liquid electrodes, which were stabilized by vortex and reverse vortex flow of gas. Dynamic plasma-liquid system using the DC discharge in a reverse vortex gas flow of tornado type with a "liquid" electrode was investigated recently [3 - 5]. Plasma-liquid system (PLS) with rotational gliding arc (RGArc) with one liquid electrode (LE) is a prototype of RGArc with solid-state electrodes [6 - 12], but with some modification, which are interesting for plasma technology. The peculiarity of plasma-liquid systems usage for plasmas generation is that they do not require pre-gasification of the liquid. In this regard, the research and development of plasma-liquid systems with RGArc with one liquid electrode for energy technologies is an urgent task.

1. EXPERIMENTAL SETUP

Schematic view of the plasma-liquid system (PLS) with rotational gliding arc is shown in Fig. 1.

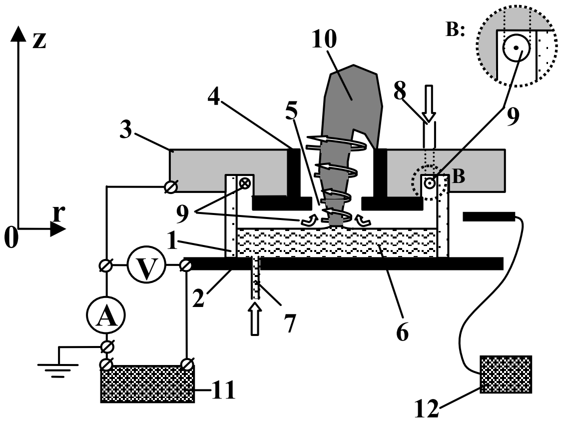

Fig. 1. Schematic diagram of experimental setup

It consists of a quartz chamber (1) cylindrical shape, which hermetically closed metal top and bottom flanges. The height of the camera is 30 mm and diameter 90 mm. Bottom flange (2) is made of stainless steel. The upper flange (3) is made of duralumin and contains a copper sleeve (4) which has a hole in the center (5) diameter of 14 mm and a length of 5 mm. Quartz chamber (1) filled with liquid (6), its level has been maintained by the injection pump through the aperture (7). Gas injected into the system through the aperture (8). Gas flow is introduced tangentially to the quartz cylinder wall (1). Rotating gas (9) moved along the surface to the axis of the quartz cylinder (1), where through the aperture (5) comes out. Plasma torch (10) was formed during the discharge burning. One end of plasma torch was located on the surface of the liquid and the other on an external part of the upper flange. The plasma torch edge, which was located on the metal surface, is rotating and gliding in the direction of air flow. The voltage between the electrodes was supplied by a DC power supply (11). The power supply provides voltages up to 7 kV. Two modes of operation can be realized in this system: liquid (LC) and solid cathode (SC). Emission spectroscopy was used for diagnostics of plasma. Emission spectra were registered using a spectral device (12) that consists of an optical fiber and spectrometer S-150-2-3648 USB. This spectrometer allows registering the emission spectra in the wavelength range 200…1000 nm.

The distance between surface of liquid and upper flange was 5 mm. Increased airflow lowers the distance between the liquid and the top flange, due to the formation of a cone of liquid on its surface. The breakdown into gas gap occurred when the distance reached a certain critical value. However, after the breakdown of gas gap the discharge was burning even in the absence of airflow (0 cm^3/s). Plasma torch was formed outside of the reactor after the breakdown of the gas gap. Length of torch initially increased with air flow increasing, reaching a length about 150 mm by air flow rate 165 cm^3/s, current 380 mA and after that length of torch began to decrease with airflow increasing.

2. RESULTS AND DISCUSSION

The discharge voltage as a function of airflow rate at different currents is shown in Fig. 2. Mode – "solid" cathode. The ballast resistance was not used. In the absence of airflow with increasing current voltage is unchanged. The supply voltage level increases with the increase of airflow rate. This may be due to a peculiarity of the impact of airflow to the discharge burning process. For large air flow increased tension ceases and the voltage is constant. This phenomenon occurs at a larger value of current when the airflow increases. However, the behavior of discharge voltage at the current of 260 mA is slightly different if currents up to 300 and 360 mA. This may be due to the fact that liquid cone is formed on the surface of the liquid cone under the influence of air flow. Cone formation reduces the distance between the liquid and the top flange. The cone height is increased when air flow is growing. However, the increasing of plasma energy input caused destruction of this cone. When currents are 300 or 360 mA, cone collapses faster than under current 260 mA. It means that there is a subdistrict, where the discharge affects mainly by air flow. If current is growing, the voltage saturates needs larger air flow.

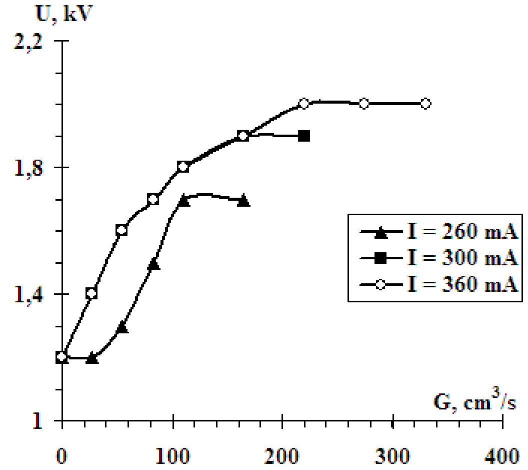

Fig. 2. The discharge voltage as a function of airflow rate at different currents

Typical emission spectra of plasma in plasma-liquid system with rotational gliding arc are shown in Fig. 3. Emission spectra were measured at the regime SC, current 340 mA, voltage 1.9 kV, air flow 165 cm^3/s. Bands of hydroxyl (OH), lines of hydrogen (H), and multiplets of oxygen (O) atoms are presented on emission spectrum of plasma inside ($z = 2.5$ mm) plasma-liquid system. Bands of hydroxyl (OH) and lines of copper (Cu) atoms are presented on emission spectrum of plasma outside ($z = 30$ mm) plasma-liquid system. The plasma torch increases if water is present. This may be due to the fact that plasma generates detonating gas, and its burning increases the plasma torch.

The low intensity of electrode material lines outside plasma-liquid system and their absence inside (see Fig. 3), demonstrates the increasing of electrodes lifetime in the RGA plasma discharge. The new state of system can be stable for an indefinite amount of time. So, significant advantage of this system is long lifetime of electrodes.

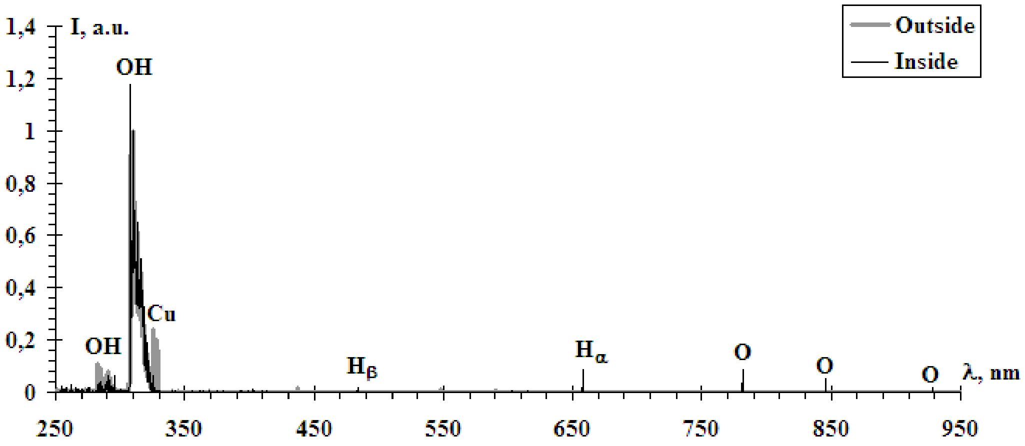

Fig. 3. Typical emission spectra of plasma inside (z = 2.5 mm) and outside (z = 30 mm) of plasma-liquid system

Temperature T_e^* population of excited electronic levels of the hydrogen atoms H was determined by the method of relative intensities (by two lines H_α – 656.3 nm and H_β – 486.1 nm). Temperature population of excited electronic levels of oxygen atoms O were determined by the Boltzmann diagrams method (777.2, 844.6, 926.6 nm).

The method of comparing experimentally measured emission spectra calculated by code SPECAIR [13] to determine the temperature population of excited vibrational T_v^* and rotational T_r^* levels of hydroxyl OH was used.

The temperature population of excited electronic levels of the oxygen atoms O, which is determined by the Boltzmann diagrams to simulate the bands of hydroxyl OH (A–X) was used. The temperature population of excited vibrational and rotational levels was specified by SPECAIR [13].

The volume which occupies plasma inside the system is on order less than the volume of plasma torch. Temperature distribution of plasma along the torch is important, because the plasma torch is injected into the reaction chamber. Axial distribution of vibrational and rotational temperature in the plasma torch is shown in Fig. 4. Emission spectra were registered by the line of sight. Measurements were carried out at a fixed value of current – 340 mA and air flow – 165 cm^3/s. Mode – "solid" cathode. $z = 0$ mm corresponds the measurements along the surface of the liquid, $z = 5$ mm – along the bottom surface of the top flange, $z = 30$ mm – along the upper surface of the upper flange. There is a one "dead" zone, in which can not be measured emission spectra. This is due peculiar structure of the upper flange.

Plasma torch reached the size to a height of 120 mm at the air flow 165 cm^3/s and current 340 mA. The intensity of the bands of hydroxyl OH decreased with increasing z. Hydroxyl bands were barely visible at the maximum accumulation for $z = 100$ mm. However, the rotational and vibrational temperature at the values of $z >$ mm from the emission spectra was difficult to determine. Since the OH bands of low intensity (274…298 nm) were used for the determination of these temperatures.

When $z = 0$ mm (along the surface of the liquid), the difference between $T_v^*(\mathrm{OH}) = 3700 \pm 200$ K and $T_r^*(\mathrm{OH}) = 3200 \pm 200$ K is 500 K, but at $z = 5$ mm (along the bottom surface of the metal flange) they are equal within the limits of error. At $z = 30$ mm difference between $T_v^*(\mathrm{OH}) = 3500 \pm 200$ K and $T_r^*(\mathrm{OH}) = 3000 \pm 200$ K is 500 K. For the $35 \leq z \leq 50$ mm difference between $T_v^*(\mathrm{OH})$ and $T_r^*(\mathrm{OH})$ remains constant 700 K, but the absolute values decrease with increasing z (see Fig. 4).

According to the obtained temperatures population of excited levels and code SPECAIR unable to determine the ratio [OH]/[O] between the concentration of hydroxyl OH and atomic oxygen O. The concentrations of hydrogen H and hydroxyl OH relative to oxygen O are shown in Fig. 5. Hydroxyl OH is on six orders of magnitude smaller than oxygen atoms O. With increasing air flow ratio [OH]/[O] begins to decrease.

This ratio [OH]/[O] has a maximum when the air flow 165 cm^3/s. This may be due to the fact that an increasing of air flow increases the power inputted into the discharge that way fluid flow increases. With further increase flow capacity varies little, and the amount of oxygen that is introduced by the flow increases. The concentration ratio [H]/[O] by using the calculated spectra according to NIST was determined. The atoms of hydrogen [H] and oxygen [O] have almost equal values.

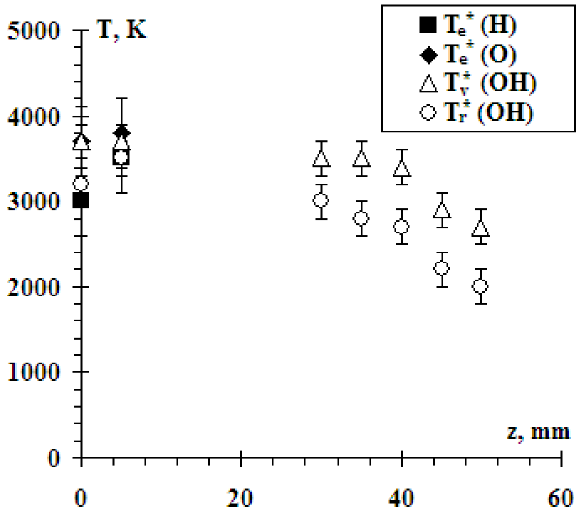

Fig. 4. Axial distribution of electronic, vibrational and rotational temperatures

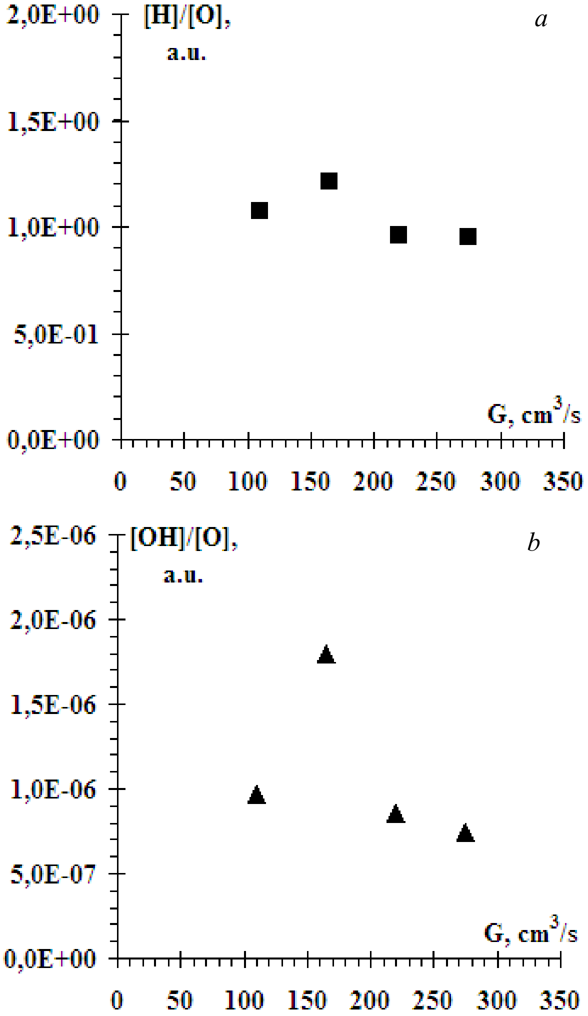

Fig. 5. The concentrations of hydrogen H and hydroxyl OH relative to oxygen O

CONCLUSIONS

Plasma is nonisothermic in the torch at the range of z 30…50 mm. The difference between $T_v^*(\mathrm{OH})$ and $T_r^*(\mathrm{OH})$ is 700 K, and their absolute values decrease with height of plasma torch ($35 \leq z \leq 50$ mm).

The main components of the plasma from interelectrode gap are OH, O, H, and major components of the plasma torch are OH, and Cu. The concentration of hydroxyl OH was low on six orders of magnitude than the concentration of oxygen O and hydrogen H atoms.

The presence of water increases the plasma torch. This may be due to the fact that plasma generates detonating gas, which burning increases the plasma torch.

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REFERENCES

1. A.S. Koroteev, V.M. Mironov, Yu.S. Svirchyk. *Plasmatrons: constructions, characteristics, calculation.* M., 1993, 286 p.
2. C.S. Kalra, M. Kossitsyn, K. Iskenderova, A. Chirokov, Y.I. Cho, A. Gutsol, A. Fridman. Electrical discharges in the Reverse Vortex Flow – Thornado Discharges // *El. Proc. Of 16th Int. Symp. on Plasma Chem. Taormina.* 2003.
3. O.A. Nedybaliuk, V. Ya. Chernyak, S.V. Olszewski. Plasma-Liquid System With Reverse Vortex Flow of “TORNADO” Type (TORNADO-LE) // *Problems of Atomic Science and Technology. Series “Plasma Physics” (16).* 2010, № 6, p. 135-137.
4. O.A. Nedybaliuk, V. Ya. Chernyak, S.V. Olszewski, E.V. Martysh. Dynamic Plasma-Liquid System with Discharge in Reverse Vortex Flow of “Tornado” Type // *International Journal of Plasma Environmental Science & Technology (5).* 2011, № 1, p. 20-24.
5. O.A. Nedybaliuk, O.V. Solomenko, V.Ya. Chernyak, E.V. Martysh, T.E. Lisitchenko, L.V. Simonchik, V.I. Arkhipenko, A.A. Kirillov, A.I. Liptuga, N.V. Belenok. Reforming of bioethanol in the system with reverse vortex air/CO_2 flow of “TORNADO” type with liquid electrode // *Problems of Atomic Science and Technology. Series «Plasma Physics» (18).* 2012, № 6, p. 178-180.
6. C.S. Kalra, A.F. Gutsol, A.A. Fridman. Gliding arc discharges as a source of intermediate plasma for methane partial oxidation // *IEEE Trans. Plasma Sci. (33).* 2005, № 1, p. 32-41.
7. A. Czernichowski. Conversion of waste Glycerol into Synthesis Gas // *19th Int. Symp. on Plasma Chem. (ISPC-19), Bochum, Germany, July 26-31.* 2009, 4 p.
8. J.M. Cormier, I. Rusu. Syngas production via methane steam reforming with oxygen: plasma reactors versus chemical reactors // *J. Phys. D: Appl. Phys. (34).* 2001, p. 2798-2803.
9. J.M. Cormier, I. Rusu, A. Khacef. On the use of a magnetic blow out glidarc reactor for the syngas production by stem reforming // *16th International symposium on plasma chemistry, Taormina.* 2003.
10. V. Chernyak. Gas discharge plasma in dynamics system as a noneqilibrium plasma sources // *Proc. 3rd Czech-Russian Seminar on Electrophysical and Thermophysical Processes in Low-temperature Plasma, Brno, November 16-19.* 1999, p. 94-99.
11. O.A. Nedybaliuk, V.Ya. Chernyak, E.V. Martysh, T.E. Lisitchenko. System with plasma injector of hydrocarbons with high viscosity // *Proc. of the VIII International Conference “Electronics and Applied Physics”, October 24-27, 2012, Kyiv, Ukraine.* 2012, p. 148-149.
12. O.A. Nedybaliuk, V.Ya. Chernyak, E.V. Martysh, T.E. Lisitchenko, O.Yu. Vergun, S.G. Orlovska. Plasma assisted combustion of paraffin mixture // *Problems of Atomic Science and Technology. Series «Plasma Physics» (19).* 2013, № 1, p. 219-221.
13. C.O. Laux, T.G. Spence, C.H. Kruger, R.N. Zare. Optical diagnostics of atmospheric pressure air plasma // *Plasma Source Sci. Technol. (12).* 2003, № 2, p. 125-138. SPECAIR: http://www.specair-radiation.net

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СВОЙСТВА ПЛАЗМЕННО-ЖИДКОСТНОЙ СИСТЕМЫ С ОДНИМ ЖИДКИМ ЭЛЕКТРОДОМ

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Представлены результаты исследования вращательной скользящей дуги с жидким электродом. Исследованы спектры излучения плазмы вращательной скользящей дуги с жидким электродом. Измерена зависимость напряжения разряда от величины потока воздуха. Определены электронные T_e^*, колебательные T_v^* и вращательные T_r^* температуры. Исследовано распределение температур вдоль плазменного факела.

ВЛАСТИВОСТІ ПЛАЗМОВО-РІДИННОЇ СИСТЕМИ З ОДНИМ РІДКИМ ЕЛЕКТРОДОМ

О.А. Недибалюк, О.В. Соломенко, В.Я. Черняк, Є.В. Мартиш, І.І. Федірчик, І.В. Присяжневич

Представлено результати дослідження обертової ковзної дуги з рідким електродом. Досліджено спектри випромінювання плазми обертової ковзної дуги з рідким електродом. Виміряно залежність напруги розряду від величини потоку повітря. Визначено електронні T_e^*, коливні T_v^* та обертові T_r^* температури. Досліджено розподіл цих температур вздовж плазмового факела.