PROPERTIES OF SECONDARY DISCHARGE IN PLASMA-LIQUID SYSTEM BASED ON ROTATING GLIDING DISCHARGE

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This paper presents the results of secondary discharge based on rotating gliding discharge study in plasma-liquid system at atmospheric pressure. Discharge electrical parameters were investigated and geometrical parameters of the discharge channel were identified. In addition, the composition of the plasma and its temperatures (rotation and vibration temperatures) were determined. The discharge channel is broad and diffuse in the investigated range of parameters. This fact and the current-voltage characteristics indicate that this is a glow discharge. The large area of plasma-liquid interface allows efficient usage of such discharge for liquid processing for disinfection or pollutants destruction.

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INTRODUCTION

A formation of thin current channels is quite typical for self-sustained plasmas ignition at atmospheric pressure. In particular, this behavior is common for gliding discharges (GD) [1] and rotating gliding discharges (RGD) [2]. In cases when the main purpose is generation of larger plasma volumes (or treatment of larger surfaces) the thin current channels formation considered as the negative effect. This become the main reasons that plasma-liquid systems (PLS) did not find major application, even considering that laboratory scale tests of water purification and sterilization in such systems was successful.

To resolve this issue the GD and RGD discharge systems where used. The main concept for both this systems is constant movement of discharge area in a certain volume or over a certain surface. Another way to solve mentioned issue is usage of secondary discharge. In this case, plasma spread over at larger liquid surface for treatment (at least at low pressure [3]). Using of secondary discharge allow to control value of the electric field inside the liquid and at the liquid surface.

Selectivity is another important issue in the development of plasma-chemical systems. Control of plasma-chemical processes in PLS can be realized by controlling of the plasma parameters. For example, a near electric field determines the energy of charged particles that come from the plasma to the treated liquid. Usually, this parameter settled for the selected conditions (the type of working liquid and gas). However, this parameter can be modified with secondary discharge systems [3].

RGD is a good choice as a maintenance discharge. It provides enlarged continuous operation time due to heat load reducing by means of increase the discharge motion area [4, 5]. Furthermore, systems based on the RGD are inexpensive and have a simple construction.

EXPERIMENTAL SETUP

The scheme of plasma-liquid system is shown in Fig. 1.

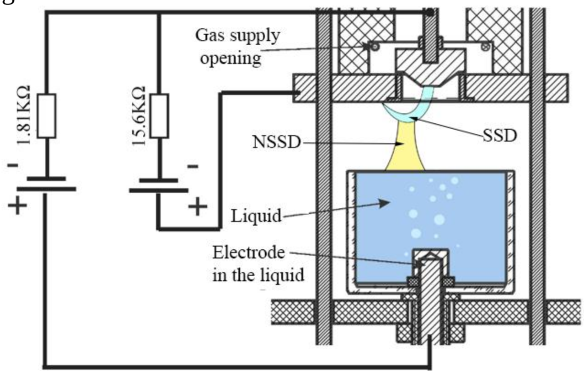

Fig. 1. The scheme of studied plasma-liquid system

Secondary or non-self-sustained (NSSD) is supporting between the liquid surface and the self-discharge channel (SSD). Rotary sliding discharge is used as SSD in this system. The plasma gas is entered through two tangential channel. The rotation of the SSD is due to the gas stream rotation. A liquid is below RGD the liquid in glass container. The electrical potential is transmitted to the liquid through the electrode in the bottom vessel. Distilled water was used as the liquid.

Some plasma thermodynamic parameters (rotation and vibration temperatures) were determined by optical emission spectroscopy. Discharges (SSD and NSSD) power supply was from two independent DC power sources with 7 kV maximum voltage. Power sources polarity shown in Fig. 1. Limitation of maximum current and discharge mode stabilization were realized by means of ballast resistors [6].

Nikon D7000 camera was used to monitor the discharge. The CCD-based spectrometer Solar TII (S-150-2-3648 USB) was used to measure plasma emission spectra. Some thermodynamic parameters of plasma (temperatures of rotation and vibration levels) were determined by optical emission spectroscopy. Using this system, electrical parameters of the discharge, namely the current-voltage characteristics and parameters of the reciprocal influence of discharges in it have been studied.

EXPERIMENTAL RESULTS

The current-voltage characteristics (CVC) of the SSD at different air flow velocities are shown in Fig. 2.

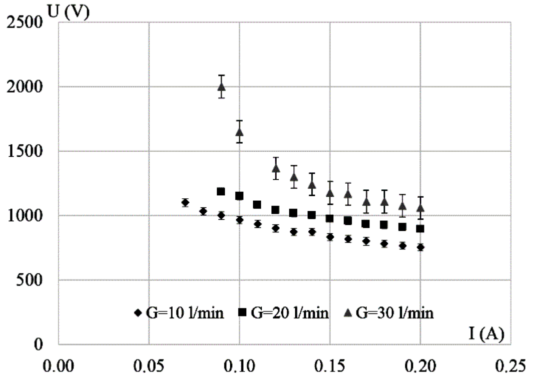

Fig. 2. The current-voltage characteristics of the SSD

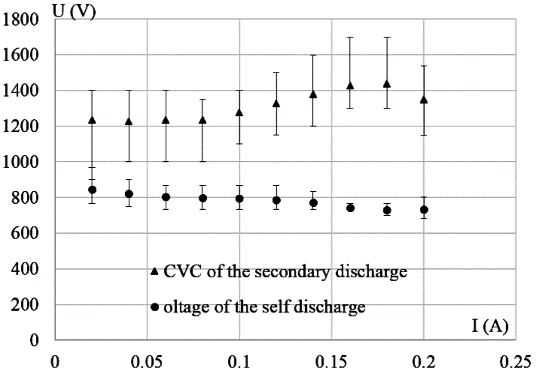

Fig. 3. The CVC of the secondary discharge and the influence of secondary current on the voltage of the rotating gliding arc (SSD current is 160 mA, the air flow rate is 10 l/min)

Falling character of CVC are common for arc discharge with the self-installed length as well as for glow discharge [6]. The rapid rise of voltage at low currents and the air flow of 30 l/min corresponds to the unstable discharge. The reduction of voltage with increasing current is corresponding to nature of the arc and to the glow discharges. The analysis of the emission spectra demonstrates the type of discharge more clearly.

The CVC of NSSD, as well as the dependence of the SSD voltage from the secondary discharge current, are shown in Fig. 3. The voltage of the secondary charge is not dependent on current within the measurement error. Besides, visible area of plasma-liquid contact increases with raising current values. This behavior is typical for secondary discharges, and glow discharges [6].

The composition of the plasma and its thermodynamic parameters were determined from studies of emission spectra. Plasma emission spectra in the range of 230…400 nm are shown in Fig. 4.

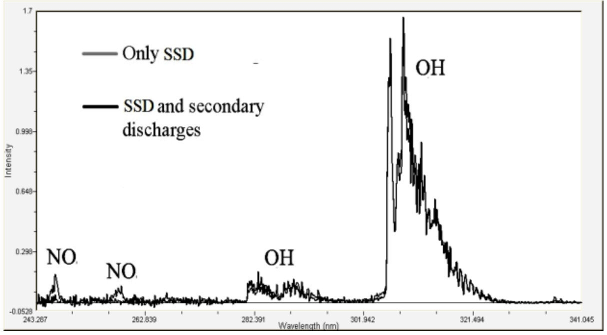

Fig. 4. The emission spectra of the plasma in the spectral range of 230…400 nm normalized to intensity on wavelength of 309 nm. SSD current is 160 mA, voltage is 960 V, the secondary discharge current is 80 mA, voltage is 1200 V

Both spectra are normalized at the high-intensity hydroxyl band. Comparison of the spectra obtained from SSD only and SSD+NSSD discharges shows that the intensity of the nitrogen monoxide compounds is significantly smaller regarding the hydroxyl compounds in the second case. The emission spectra analysis shows that plasma generated by the system is non-isothermal. The calculated values of temperatures have shown that vibration temperature higher in cases of SSD (T^*_v=4000±500 K) than SSD+NSSD (T^*_v=3250±500 K). The rotation temperature is same for both cases (T^*_r=3000±500 K). Thus it is possible to conclude that the generated discharge has an analogy with the glow one because of emission lines of electrode material absent and CVCs are near of CVCs of glow discharge.

Photo-capturing was used to determine the geometric constraints of the discharge. Pictures with different shutter speeds were used to eliminate blurring due to movement of the discharge channel. Photographs of the discharge at 5 l/min air flow are shown in Fig. 5.

Distinct current channels in this mode are not observed, even at higher shutter speeds. The blue emission was observed near the liquid surface where plasma was touching it. Apparently, the ionization-overheating instability under these conditions is weak. Wide area of interactions between plasma and liquid testifies this. It should also be noted that the liquid surface is not significantly distorted when this gas stream.

The situation is changing with increasing gas flow. Images taken at 10 l/min of air flow is shown in Fig. 6. Area of plasma-liquid contact is larger than in the previous case. However, at lower exposure, it shows that the size of the plasma region, which is in contact with liquid, decreased. This trend continues with the flow of 20 l/min (Fig. 7).

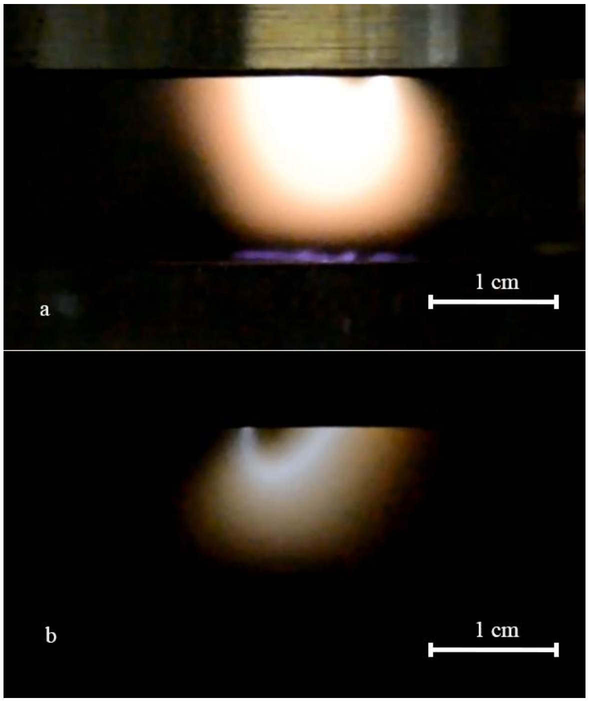

Fig. 5. The discharge photos at air flow of 5 l/min were redistricted with exposures of 17 ms (a) and 1 ms (b). SSD current is 160 mA, secondary discharge – 80 mA

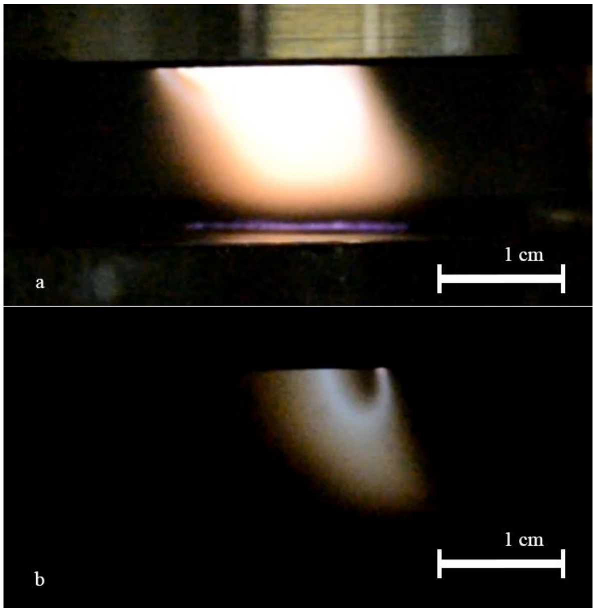

Fig. 6. The discharge photos at air flow of 10 l/min, were redistricted with exposures of 17 ms (a) and 1 ms (b). SSD current is 160 mA, secondary discharge – 80 mA

Current channel movement rate is increased in conjunction with air flow. This leads to a blurring of images taken at slow shutter speeds. However, at shorter exposures, it is seen that the instantaneous contact area decreases. The secondary discharge has observable individual current channels at air consumption 20 l/min.

Reducing the diameter of the current channel, and the emergence of the current cord points out that an air flow increase in the system, more and more manifested ionization – overheating instability. Furthermore, the air flow distorts the liquid surface. This makes the electric field in the system more heterogeneous, which in turn leads to appearance of separate current channel.

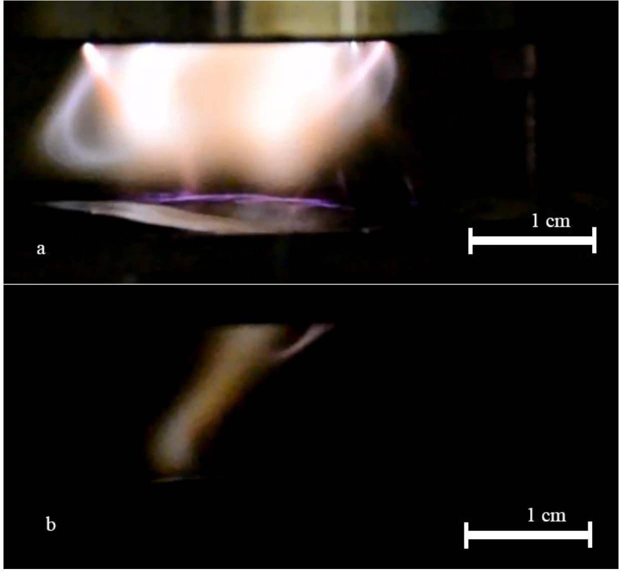

Fig. 7. The discharge photos at air flow of 20 l/min, were redistricted with exposures of 17 ms (a) and 1 ms (b). SSD current is 160 mA, secondary discharge – 80 mA

DEGRADATION OF PHENOL IN THE PLASMA-LIQUID SYSTEM

Plasma-liquid systems often applied as a tool for destruction of pollutants. Phenol is one of the most common pollutants. Phenol solution with a concentration of 0.02 M was used in our studies. Self-discharge current was 160 mA. Secondary discharge current was 80 mA. Electrical energy spent per one destroyed molecule is a parameter of the energy efficiency of the process.

The changes of phenol concentration were monitored by means of absorption spectroscopy method. The solution volume in the system was 130 ml. Processing time varied in range of 1…5 minutes.

Dependence of the degradation energy cost as a function of processing time shown in Fig. 8.

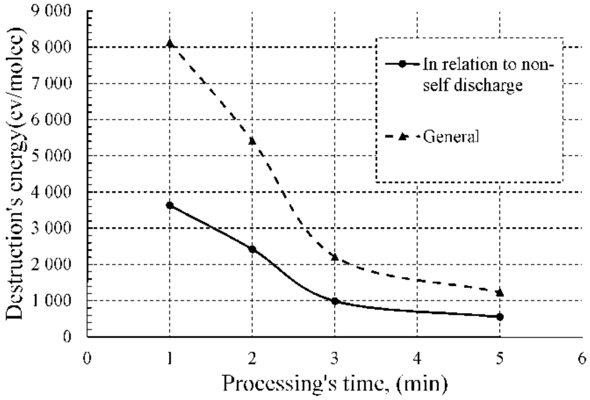

Fig. 8. Dependence of the energy cost of degradation on the processing time

Presumably, secondary discharge plays a major role in influencing the liquid. For this reason, the calculation of the energy cost of the degradation was carried out. For this purpose a two ways have been applied. One of them is based on taking into account the total energy (Fig 8, dashed line). Another one, taking into account only energy embedded into the secondary discharge (Fig. 8, solid line). Both values decreased with increasing treatment time. In addition, the total energy consumption can be reduced by decreasing energy input in SSD.

Furthermore, the total energy consumption can be reduced by energy input to the SSD attenuation.

CONCLUSIONS

The secondary electric discharge in a plasma-liquid system at atmospheric pressure has an analogy with glow one. The current-voltage characteristics and the absence of metal lines in the emission spectra indicated it. In addition, it is well-known that glow discharge can be characterized by non-isothermal plasma more better than arc.

The secondary discharge is diffuse in case of small (about 5 l/min) gas flows. Channel movement rate is increased due to air flow augmentation. At the same time, the instantaneous contact area between plasma and liquid decreases.

This system can be utilized for water disinfection, degradation of contaminants and water treatment.

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СВОЙСТВА ВТОРИЧНОГО РАЗРЯДА В ПЛАЗМЕННО-ЖИДКОСТНОЙ СИСТЕМЕ, ОСНОВАННОЙ НА ВРАЩАЮЩЕМСЯ СКОЛЬЗЯЩЕМ РАЗРЯДЕ

Д.К. Гамазин, В.В. Юхименко, В.Я. Черняк, Е.В. Присяжная, Е.В. Мартыш, В.А. Бортышевский, Р.В. Корж

Представлены результаты исследований вторичного разряда в плазменно-жидкостной системе при атмосферном давлении. Были определены электрические параметры разряда, а также геометрические параметры разрядного канала. Также были определены компонентный состав и температуры (заселения возбуждённых вращательных и колебательных уровней) плазмы. Разрядный канал широкий и диффузный, в исследуемом диапазоне параметров. Это, наряду с поведением вольт-амперных характеристик, свидетельствует о том, что разряд тлеющий. Большая площадь взаимодействия плазмы с жидкостью обеспечивает эффективное использование таких систем для обработки жидкости с целью её дезинфекции и разрушения загрязнителей.

ВЛАСТИВОСТІ ВТОРИННОГО РОЗРЯДУ В ПЛАЗМОВО-РІДИННІЙ СИСТЕМІ, ЩО БАЗУЄТЬСЯ НА ОБЕРТОВОМУ КОВЗНОМУ РОЗРЯДІ

Д.К. Гамазін, В.В. Юхименко, В.Я. Черняк, О.В. Присяжна, Є.В. Мартиш, В.А. Бортишевський, Р.В. Корж

Представлено результати досліджень вторинного розряду в плазмово-рідинній системі при атмосферному тиску. Були визначені електричні параметри розряду, а також геометричні параметри розрядного каналу. Також були визначені компонентний склад та температури (заселення збуджених обертальних та коливальних рівнів) плазми. Розрядний канал широкий та дифузійний, в досліджуваному діапазоні параметрів. Це, з урахуванням поведінки вольт-амперних характеристик, свідчить про те, що розряд тліючий. Велика площа взаємодії плазми з рідиною забезпечує ефективне використання таких систем для обробки рідини з метою її дезінфекції та руйнування забруднювачів.