The appearance of shock waves in the plasma electrolytic processing

D.G. Denisov¹, N.F. Kashapov¹, R.N. Kashapov²
¹ Kazan Federal University, 18 Kremlyovskaya St
² Kazan Physical -Technical Institute, Sibirsky tract 10/7

E-mail: kashramil.88@mail.ru

Abstract. In this paper, we have been tasked to investigate the transitional regime, to identify the main physical phenomena and give them a qualitative explanation. As a result of experimental researches, have been proposed and discussed possible mechanisms for generating shock waves in the transition region.

Introduction
Discharges in liquids for a long time are interesting to researchers, due to the presence of a wide range of physical and chemical phenomena. One of the kinds of these systems is discharges with liquid electrodes when one of the electrodes (anode or cathode) is an electrolyte solution. Well enough investigated the discharge in a stationary mode at voltages higher than 200 V while the metal electrode immersed and situated above the surface [1]. These systems have been used in the processes of thermal effects [2], in the processes of plasma-chemical treatment processes [3], in the formation of protective coatings [4], in the process of cleaning fluid from toxic pollution. However, it remains unclear mechanism of transition from electrolysis in the stationary mode burning of the discharge [5] and did not explain the reasons for the physical and chemical phenomena that occur at the same time. In this paper, we have been tasked to investigate the transitional regime, to identify the main physical phenomena and give them a qualitative explanation.

Experimental
For research the transition regime was used experimental setup, shown in Fig. 1. It consists of the electrolytic cell 1, power supply 2, test equipment 3, shunt 4, the electrode system 5, thermometer 6, high-speed video cameras 7 and ammeter 8.

System electrical power is a DC power supply with continuously variable voltage [6]. The power supply consists of a diode bridge and laboratory autotransformer adjustment type 1M with a voltage range from 1 to 240 V, 50 Hz. Used the work in two modes, the first - when the applied voltage obtained after full-wave rectification, and the second - with the additional use of a capacitive filter capacitance C = 1560 uF.

Research of the transition regime conducted on the anode made of graphite and steel grades of Russian steel #3, 12X18H10T. To prevent resizing dielectric protective cover, which leaves open only a strictly defined part of the electrode, was worn on the area of the anode. The area of the anode was 0.65 cm². As cathode was used copper plate, an area of 35 cm². The electrolytic bath is filled with...
researched electrolytes in necessary concentration and composition. Aqueous solutions (NaCl, Na₂CO₃, NaOH) were used as the working fluid.

![Fig. 1 Functional diagram of the experimental setup](image)

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![Graph a](image)

![Graph b](image)

![Graph c](image)

Fig. 2. CVC of plasma electrolytic process. a - 5% aqueous solution of NaCl; b - 5% aqueous solution of Na₂CO₃; c - 5% aqueous solution of NaOH. (1) - pulsed (2) - smoothed.

The main operating parameters of the system are: the voltage on the electrodes, the magnitude of the discharge current, the current density at the electrodes, the electrolyte temperature and the
temperature of the anode. Changing the shape of voltage and current at the time of discharge ignition was determined using an oscilloscope FLUKE 190-062 SCOPEMETER 2CH 60MHz 625 MS / s, time base varies from 5 ns to 60 s. The relative measurement error did not exceed 0.025%. Measure the voltage at the anode was carried out using a digital universal measuring device APPA-207, the relative error of measurement is 0.5%. With a digital multimeter APPA 305 temperature measurement was carried out of the electrolytic cathode in using the chromel- copel thermocouple. Measuring the temperature of the anode was carried out by thermometer Fluke 62 Max. Research of fast processes in the transition region of plasma electrolytic processing was carried out by using high-speed video camera Fastec HiSpec 4. The shooting speed was regulated, at a maximum resolution of 1696 * 1710 amounted to 523 frames per second at 320 * 240 - 14 781 frames per second.

Processing of the results was carried out taking into account the measurement uncertainty.

Before the research of the transition region current-voltage characteristics of plasma electrolytic process in a pulsed mode and smooth were obtained, presented in Fig. 2.

When using a capacitive filter established that the transition occurs during 20 millisecond. From the end of the electrode gas bubble growing, which gradually rises up and covers the entire surface.

Also, there is a strong 90% drop in current and voltage increase by an average of 15 V. Of interest is the transition in the pulse mode. When using a full-wave voltage of generation shock waves were observed. Current-voltage characteristics of full-wave mode can be divided into three sections. The first section from 0 to 70 V. This area corresponds to the course of only electrochemical reactions. The second region 70 V to 180 V – it is the burning of separate microdischarges at the anode surface. Precisely in this range, shock waves are generated. In the third area of 180 V and above there is a glow of vapor-gas layer around the electrode without the occurrence of certain microdischarges. The process discharge burning occurs intermittently, with each new pulse, appearing again and again. Nature of the electrolyte is generally not effects the picture of occurring physical processes. The difference lies in the strength of the current and the borders of the transition from the electrolysis mode of burning anode discharges. The use of a graphite electrode, also not show value changes.

Consider a series of photographs presented in Fig. 3, (one frame corresponds to one millisecond) full-wave mode, obtained at the average voltage of 80 V and a current of 20 A. It can be divided into three stages. First - electrochemical reaction, frame №1. Further, when the ignition voltage on the anode surface is initiated of burning anode microdischarges - this is the second stage, which lasts 3 ms.( 2, 3 and 4 frames). The third stage - is the formation and growth of gas bubbles (5, 6 frame) centered on the place where previously burned microdischarges. Thus, the period of the current 10 ms consists of the area of electrochemical reactions lasting 4 ms, of burning gas microdischarges - 3 ms, the formation and growth of the gas bubbles - 3 ms. But it should be noted that the development and exit gas bubble to the surface of electrolyte may take up to 20 ms.

Let's look at the possible mechanisms to generate shock waves in the transition area. The first of the options is the presence of microbubbles, which are polarized in an electric field and under the periodic influence of 100 Hz are beginning to waver. Characteristic feature is presence of sound, with no visible light radiation. Further may occur two possible options: the collapse of the bubble and the
formation of a shock wave (similar to cavitation) or the breakdown of a gas bubble, a sharp drop in pressure in the bubble after quenching of the discharge and the collapse of the bubble, which also lead to the emergence of the shock wave.

The second possible mechanism is that the calefaction of the discharge channel occurs inside the cavity of the leader, in the initial stage of calefaction does not occur over the entire cross section of cavity leader channel. Thus, at the initial moment, we are seeing the formation of a leader in the liquid and its germination in environment at a small distance, and then localized calefaction in the gas discharge.

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