The effect of gas injection on energy characteristics of high-current gas discharge with liquid electrolyte cathode

K K Tazmeev¹, A K Tazmeev¹ and I G Dautov²

¹ Kazan Federal University, Naberezhnye Chelny Institute, Mira Street 68/19, Naberezhnye Chelny, 423810, Russian Federation
² Kazan National Research Technical University named after A.N. Tupolev, K. Marx str. 10, Kazan, 420111, Russian Federation

E-mail: tazmeevh@mail.ru

Abstract. A gas discharge with flowing liquid electrolyte cathode was studied experimentally in high-current combustion conditions under conditions of gas injection into the discharge chamber. The interelectrode distance was 20 cm. Aqueous solutions of sodium chloride with specific electrical conductivity of 10⁻¹² mS/cm were used as electrolyte. The discharge current varied within 14–20 A. The studies were carried out with air blowing at a mass flow rate of up to 2.2 g/s. It is shown that air blowing leads to an increase in the discharge current and decrease heat losses through electrodes.

1. Introduction

Plasma produced in gas discharges with liquid electrolyte cathode is promising for use in plasma chemical reactors designed for energy-intensive plasma technologies. For example, in [1–4] possibility of using such plasma for processing of waste polymeric materials were shown. The discharge burned in small vertical gap between liquid electrolyte and metal electrode. Its height was within 3–4 mm. Such small sizes did not allow introduction of reagents into discharge region, where the concentration of chemically active particles is highest. Reagents were fed into the plasma stream at considerable distance from discharge region. Nevertheless, synthesis gas with a fairly good chemical composition was obtained. The process was slow and energy-intensive. Reducing energy intensity and accelerating the process is possible when reagents are introduced directly into discharge region. However, under these conditions, gas discharge is poorly understood. There are works in which studies were carried out at low currents [5–6]. With a multiple increase in current, the physical picture of the phenomena can change significantly. In this connection, the aim of this work was to study a gas discharge in high-current combustion modes when gas is injected into an extended discharge region.

2. Experiment

In figure 1 shows diagram of gas discharge device (plasma generator) together with gas supply system. The discharge is ignited between cathode assembly 1 and anode 2 inside chamber, which consists of housing 3 and lining 4. The output channel of discharge chamber is 50 cm elongated and equipped with metal casing 5. A detailed description of the cathode assembly is given in [7]. The arrows indicate directions of electrolyte flows. The electrolyte circulates through cathode assembly with fixed mass velocity m. Part of electrolyte is sprayed from open surface and enters discharge region. The
inter electrode distance $l$ is 20 cm. The anode is copper rod with diameter of 25 mm. It is cooled by water. The housing 3 of discharge chamber is made of asbestos-cement materials, and lining 4 is made of refractory bricks.

![Figure 1. The experimental setup.](image)

Gas was supplied into the interelectrode gap from the anode side through channel 6 directed at an angle of 30 degrees to the axis of discharge chamber. In the experiments, compressed air from compressor 7 was used. Its flow rate $G_{\text{air}}$ was monitored using an exemplary pressure gauge 8 and float rotameter 9.

The electric power source was a three-phase two-half-period rectifier connected to the secondary windings of step-up transformer. Voltage ripples were smoothed by a C-L-C filter. At the moment of discharge ignition, the current was limited by the ballast resistor, and then its resistance was reduced to zero.

An aqueous solution of sodium chloride with a specific electrical conductivity $\sigma$ in the range of 10–12 mS/cm was used as a liquid electrolyte cathode. In the process of burning discharge, electrolyte is spent on the formation of plasma stream. The mass rate $G$ of electrolyte loss can be considered numerically equal to the mass flow rate of plasma stream. The electrolyte loss was compensated by addition of distilled water during operation of plasma generator.

To study thermal and electrical characteristics, methods used were described in [7–8]. The temperature in plasma stream was measured with PR-30/6 platinum rhodium thermocouple at different distances $z$ from anode. The thermocouple was moved using a coordinate device in three mutually perpendicular directions.

3. The results of the experiments and their analysis

![Figure 2. Photographs of plasma stream at exit of plasma generator and the temperature distribution](image)
along the stream. \( m = 15 \text{ g/s}. \) (a) \( G_{\text{air}} = 0; \) (b) \( 1.5 \text{ g/s}. \)

In figure 2 shows photographs of plasma stream at exit of plasma generator and temperature distribution along the stream. The conditions of discharge burning corresponding to photographs differ by only one external factor. These photographs were taken: in the absence of air flow (figure 2a) and in the presence of it (figure 2b). As can be seen, air blowing has a significant effect on formation of plasma flow. The luminous flame is much longer and wider. Moreover at the same axial coordinates \( z \) the temperature rises by 300-400 K. Such results are somewhat unexpected, because mixing plasma with cold air was supposed to lower the temperature. To identify the causes of this effect, a more thorough analysis of the processes in the plasma generator is required.

**Figure 3.** Oscillograms of current and voltage. \( m = 15 \text{ g/s}. \) (a) \( G_{\text{air}} = 0; \) (b) \( 1.5 \text{ g/s}; \) (c) transition from the non-gas combustion mode \( (G_{\text{air}} = 0) \) to injection mode \( (G_{\text{air}} = 1.5 \text{ g/c}). \)

The occurrence of another effect is recorded in the oscillograms of current and voltage (figure 3). From comparison of the oscillograms shown in figure 3a and 3b, it is seen that when air is injection in, the amplitude of its current pulsations decreases significantly. This effect is even more clearly manifested during the rapid transition from the combustion mode without gas to the regime with injection (figure 3c). It should be noted that, in a glow discharge, the dependence of pulsations of electrical parameters on gas flow rate is also observed [9, 10]

In figure 4 shows the main energy characteristics of plasma generator. As can be seen, when air is injected, a certain increase in the power consumption \( N \) occurs. Such an increase indicates the influence of gas flow on the mechanism of electric current flow between liquid electrolyte cathode and metal anode.
Heat losses through the electrodes are relatively small. When air is injected in, the heat loss power through $Q_a$ anode is significantly reduced. This decrease is caused by additional cooling of anode by air flow.

**Figure 4.** The power of plasma generator ($N$) and heat loss through the electrodes ($Q_c$ и $Q_a$) in depending on air flow rate $G_{air}$. $m = 15$ g/s. 1 - $N$; 2 - $Q_c$; 3 - $Q_a$.

4. Conclusions
The following regularities that occur under gas injection conditions were experimentally revealed: 1) the temperature of plasma at the exit of plasma generator is rises; 2) the discharge power increases at a constant voltage on plasma generator; 3) reduced heat loss through metal anode.

**Acknowledgments**
This work was financially supported by the RFBR and the Government of the Republic of Tatarstan in the framework of the research project No. 18-42-160011.

**References**
[1] Fridland S V, Tazmeev A K and Miťakhov M N 2006 Vestnik Kazanskogo tekhnologicheskogo universiteta No. 6 10
[2] Tazmeev A K, Fridland S V and Miťakhov M N 2006 Vestnik Kazanskogo tekhnologicheskogo universiteta No. 6 43
[3] Tazmeev A K and Tazmeeva R N 2017 Journal of Physics: Conference Series 789 012058
[4] Tazmeev A Kh and Tazmeeva R N 2018 Journal of Physics: Conference Series 1058 012036
[5] Petrov A E et al. 2011 Gorenje i plazmohimiya 9(3) 160
[6] Kashapov N, Kashapov R and Kashapov L 2018 Journal of Physics D: Applied Physics 51(49) 494003
[7] Tazmeev Kh K, Arslanov I M and Tazmeev G Kh 2014 Journal of Physics: Conference Series 567 012001
[8] Miťakhov M N, Tazmeev Kh K, Tazmeev A Kh and Fridland S V 2006 Journal of Physics and Thermophysics 79(3) 532
[9] R F Yunusov and M M Garipov 2019 Journal of Physics: Conference Series 1328 012101
[10] R F Yunusov and M M Garipov 2019 Journal of Physics: Conference Series 1328 012102