Application of gas discharge with liquid electrolytic cathode to create flow of steam-water plasma

G K Tazmeev¹, K K Tazmeev¹ and B A Timerkaev²
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: gktazmeev@kpfu.ru

Abstract. A gas discharge with flowing liquid electrolyte cathode was experimentally investigated under combustion conditions inside an extended chamber with walls made of refractory material. The copper anode was located above the cathode at a distance of 20 cm. The length of the output channel was 50 cm. Heavily diluted aqueous solutions of sodium chloride were used as the electrolyte. The mass velocity of the electrolyte ranged from 8-16 g/s. A three-phase two-half-wave rectifier with voltage at the output of 2100 V served as a power source. The discharge burned stably without a ballast resistor. A plasma flow with mass velocity of 1.0-1.7 g/s in the power range of 25-30 kW was obtained. The total heat loss through electrodes did not exceed 30% of power consumption.

1. Introduction
The liquid electrolyte used as a cathode is subjected to intense heat. The electrolyte evaporates, sprays, partially enters in discharge region and participates in the formation of plasma. The amount of working electrolyte decreases. The electrolyte loss increases with increasing current [1-3]. The mass rate of decrease depends on heat release inside electrolyte and conditions for heat removal from electrolyte [2]. In practice, discharge-burning modes are implemented in which electrolyte decreases at a mass velocity of up to 1.5 g/s [3]. Plasma flows with such mass flow rates are quite acceptable for energy-intensive plasma technologies. Therefore, powerful gas discharges with liquid electrolyte cathode can be considered along with arc plasmatrons as sources of energy in plasma-chemical processes, in particular, in plasma gasification of carbon-containing raw materials. The aim of this work was to study the possibilities of using gas discharge with liquid electrolyte cathode to create a steam-water plasma flow in the power ranges 25-30 kW.

2. Experiment
In figure 1 shows diagram of gas discharge device (plasma generator) with power source. The discharge is ignited between the cathode assembly 1 and the anode 2 inside the chamber, which consists of a housing 3 and a lining 4. The output channel of discharge chamber is 50 cm elongated and equipped with a metal casing 5. A detailed description of the cathode assembly is given in [3]. The arrows indicate the directions of the electrolyte flows. The electrolyte circulates through cathode assembly with fixed mass velocity m. Part of electrolyte is sprayed from an open surface and enters discharge region. The
interelectrode distance \( l \) is 20 cm. The anode is a copper rod with a 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.

Electric power was supplied from a three-phase two-half-period rectifier connected to the secondary windings of the step-up transformer. Voltage ripples were smoothed by a C-L-C filter. The current was changed by stepwise variation of the ballast resistor \( R \).

Liquid electrolyte cathode served as aqueous solutions of sodium chloride with a specific gravity electrical conductivity \( \sigma \) in the range of 10-15 mS/cm. When using such electrolyte solutions provides a stable burning of discharge at big interelectrode distances [4].

In the process of burning discharge the electrolyte is spent on 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 the addition of distilled water during the operation of plasma generator.

To study thermal and electrical characteristics, methods used were described in [2-3]. The temperature in plasma stream was measured with platinum rhodium thermocouple PR-30/6 at different distances \( z \) from the anode. The thermocouple was moved using a coordinate device in three mutually perpendicular directions.

### 3. The results of the experiments and their analysis

In figure 2 shows the oscillograms of current \( I \) and voltage \( U \) on plasma generator. These parameters are subject to ripple.
**Figure 2.** Oscillograms of current and voltage. $\sigma = 11 \text{ mS/m, } m = 12 \text{ g/s}$. (a) $R = 14 \Omega$; (b) $R = 0$.

As can be seen from comparison of oscillograms with increasing current the amplitude of its ripples was increases. Apparently the increase in pulsations is caused by a decrease in the resistance of the ballast resistor. Similar patterns are observed in discharge that burns in the open air [3]. The presence of ripple current and voltage is a characteristic feature of gas discharge between liquid electrolyte cathode and metal anode. Another characteristic feature of discharge is manifested when the intensity of electrolyte flow through the zone of attachment of discharge to cathode changes. Under conditions of discharge burning in open air, an increase in current occurs with an increase in electrolyte consumption [3]. Such pattern was revealed in this work. The results are presented in figure 2a.

![Oscillograms of current and voltage](image)

**Figure 2a.** Oscillograms of current and voltage. $\sigma = 11 \text{ mS/m, } m = 12 \text{ g/s}$.

**Figure 3.** Dependences of current (a) and mass flow rate of plasma (b) from mass flow rate of electrolyte, passing through cathode assembly. $\sigma = 11 \text{ mS/m, } R = 0$.

With an increase in mass flow rate of electrolyte, mass flow rate of plasma is increases (figure 2b). The patterns of changes current and mass flow rate of plasma are the same. Such correlation between these two parameters indicates the presence of a significant ion current. Ions are transferred to plasma from the cathode as part of solution droplets [5]. The more droplets atomized, the more ions enter the discharge region and the greater the current becomes.

From practical point of view, the most interesting are the modes of operation of plasma generator at zero resistance of the ballast resistor ($R = 0$) are greatest interest. In this case, the loss of electrical energy for heating ballast resistor is excluded. In figure 4 shows the energy characteristics of plasma generator obtained in operating modes without a ballast resistor.

![Dependences of current and mass flow rate of plasma](image)

**Figure 3a.** Dependences of current (a) and mass flow rate of plasma (b) from mass flow rate of electrolyte, passing through cathode assembly. $\sigma = 11 \text{ mS/m, } R = 0$.

![Energy characteristics of plasma generator](image)

**Figure 4.** The power of plasma generator ($N$) and heat loss through the electrodes ($Q_e$ and $Q_a$) in depending on mass flow rate of electrolyte $m$. $R = 0$. $\sigma = 11 \text{ mS/m}$.

Heat losses through electrodes are relatively small. The heat loss capacities through the cathode $Q_e$ and the anode $Q_a$ differ slightly. An increase electrolyte flow rate through cathode assembly leads to
some increase in the heat loss $Q_c$ and $Q_a$. In this case, the power of plasma generator $N$ is increases. The ratio of the sum of $Q_c$ and $Q_a$ to $N$ varies insignificantly. The total heat loss through electrodes does not exceed 30% of the power consumption.

Table 1 shows the results of plasma temperature measurements using a platinum-rhodium thermocouple.

**Table 1. Plasma flow temperature.**

| $z$, (sm) | $t$, °C  |
|-----------|---------|
| 55        | 1400±100 |
| 60        | 1350±100 |
| 70        | 1150±100 |
| 80        | 800±100  |

At the exit from plasma generator a plasma stream is created with a sufficiently high temperature despite considerable distance from discharge region. As the thermodynamic analysis shows at such temperatures plasma conversion of polyethylene and polyethylene terephthalate waste into synthesis gas can be carried out [4].

**4. Conclusions**

The possibility of using gas discharge with liquid electrolyte cathode to obtain a steam-water plasma stream in the power range of 25-30 kW has been experimentally shown. The main parameters of plasma flow: mass flow rate 1.1-1.7 g /s; temperature 1400 ± 100 ° C at a distance of 0.5 m from discharge region.

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