

The Creation Of High Temperature Steam Flow For Plasma Chemical Gasification Of Polymer Waste

Guzel R. Gibadullina, Almaz H. Tazmeev, Ramilya N. Tazmeeva

FSAEI VPO "Kazan (Volga region) Federal University"
420008, Kazan, Kremlevskaya str., 18, e-mail: valguz85@mail.ru

Abstract- The process of water steam plasma in the gas discharge with liquid electrolyte cathode was studied experimentally. The studies demonstrated the fact that the steam water plasma contains no ballast components, such as nitrogen in the composition of air plasma. Due to this, it is effective as a power supply, which is used in plasma-chemical reactors intended for recycling. The mechanisms of harmful oxides development such as nitrogen and sulfur oxides are suppressed in steam water plasma. Therefore, the most favorable environmental conditions will be provided.

An aqueous solution of sodium chloride in distilled water was used as an electrolyte. The experiments were carried out in the range of 4-11 A currents. The current density based on liquid cathode is maintained within 0.8-1.0 A/cm². The energy balance was studied. The heat loss on the electrodes is determined by the calorimetric method. The regularities of flow electrolyte kinematic parameter influence on the energy characteristics of the plasma generator are revealed. The optimal mode of electrolyte flow through the cathode assembly of the plasma generator is established. The heat loss on the cathode is reduced significantly due to the changes of the flow electrolyte velocity. The possibility of steam water plasma use for the gasification of organic waste is demonstrated. A salable product represented by synthesis gas is obtained from plastic waste. The chromatographic analysis of the synthesis gas is performed. It was revealed that the synthesis gas, which is formed from polyethylene waste, contains less ballast components in the form of carbon dioxide.

The prospects of plasma generator use with liquid electrolyte cathode for polymer waste gasification are determined experimentally.

Keywords: steam water plasma, liquid cathode, plasma generator, synthesis gas.

1. INTRODUCTION

At the present level of industrial development the problem of waste recycling is of paramount importance.

Not all types of waste may be disposed of by traditional burning in incinerators. For example, during an ordinary combustion of polymer wastes containing halogens highly toxic dioxins are developed [1-2]. The most promising technology of such substances utilization is plasma-chemical technology based on high-temperature plasma chemical exposure at which a useful product is obtained in the form of synthesis gas, which is the mixture of hydrogen and carbon monoxide and is a valuable energy raw material [3-6]. The main advantage of plasma-chemical technology is the versatility with respect to the type of material and small sizes which allow you to create mobile technological modules. However, the wide practical application of plasma technologies is hampered by lack of reliable plasma generators with a sufficient resource of continuous operation. Currently, arc plasma torches are used mainly as the plasma generators. The existing arc plasma torches, generally require for the operation the use of expensive inert gas as a plasma forming body, while the optimum one is water vapor in terms of plasma-chemical reactions [7-8]. An electrical arc in powerful plasma torches leads to an intensive erosion of the electrodes. Plasma systems often have to be stopped to replace the electrodes. In this paper we consider a fundamentally new plasma generator that does not have any restrictions on electrode amount.

2. EXPERIMENTAL DEVICE AND STUDY METHODS

Plasma generator and its supply system are shown schematically on Fig. 1. The gas discharge 1 was burning between the electrolyte 2, poured into the electrolytic cell 3, and a metal water-cooled anode 4. The body of the electrolytic cell 3 was made of asbestos-cement. The wall thickness made 30 mm. Current feeder 5 is mounted inside the housing 5 made of graphite. Anodes of different sizes were tested. This paper presents the experimental results obtained for the anode with the following dimensions: $a = 9$ mm, $b = 9$ mm, $c = 36$ mm, $d = 3$ mm. The anode material is a gray cast iron. It was located at the distance $h = 15$ mm from the current feeder 5.

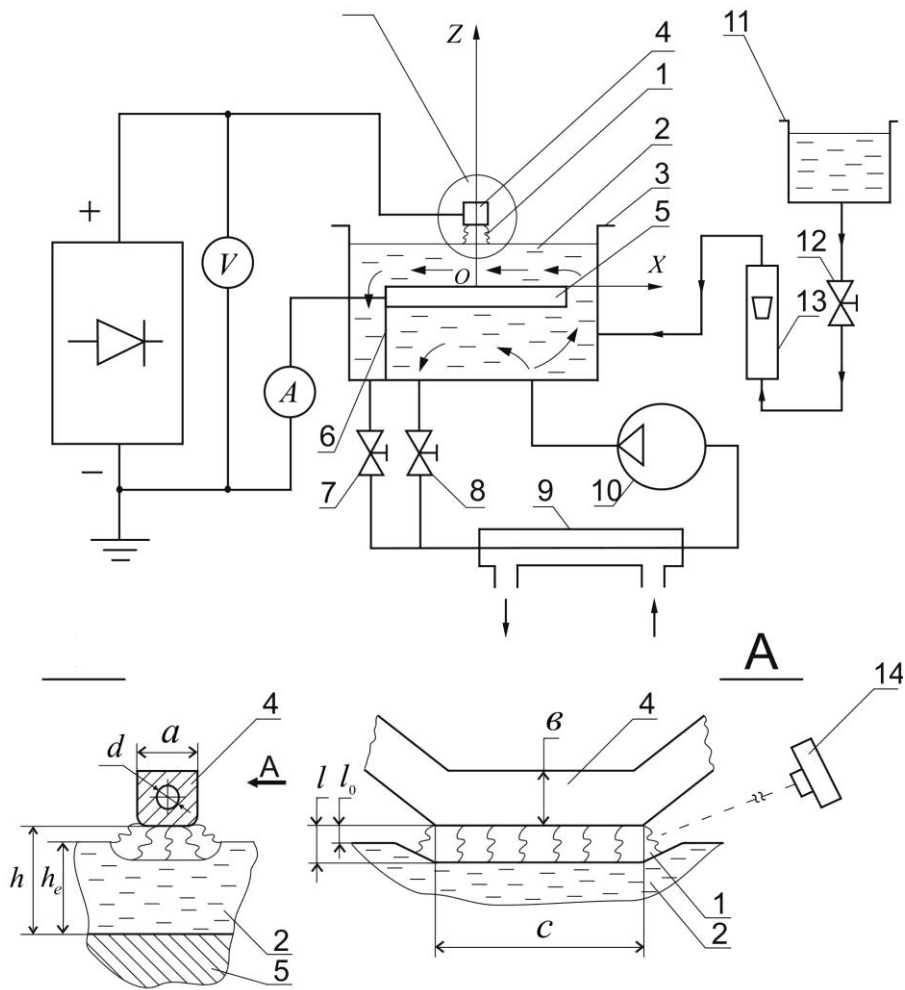


Fig. (1). – Principal scheme of experimental device

The electrolyte entering the electrolytic cell 3 flowed through it, being divided into two streams. One stream passed above the current feeder 5 (through the zone of discharge action 1), while the other one below it. The directions of their currents are indicated by arrows on the figure. The electrolyte streams on the output of the cell 3 were separated from each other by a partition 6. The upper flow of the electrolyte in a discharge area was flowed into a rectangular channel (width: 85 mm, height: 13 mm). The flow rate of the electrolyte along this channel varied using the valve 7. The consumable parameters of underflow were regulated by the valve 8.

The heat exchanger 9 was represented by a 5 m coil. The inner tube was a copper one (with the passage section diameter of 10 mm). Tap water was used as a coolant. Electrolyte circulation was created by the hydraulic pump 10 of a centrifugal type, the casing and the impeller of which are made of aluminum alloy.

The loss of electrolyte, which took place due to the evaporation under the influence of a gas discharge, was compensated by the supply of fresh electrolyte from the tank 11. The consumption of added electrolyte was regulated by valve 10 and controlled by float rotameter 13.

The source of a gas discharge electrical power was a three-phase double semiperiodic rectifier connected to the secondary windings of a step-up transformer. The adjusting of the rectified current was carried out by continuous change of voltage on the primary windings of a transformer. The negative pole of a power source was grounded. The ballast resistor in the discharge power chain discharge was absent.

The heat loss at the anode Q_a and the liquid cathode Q_k were determined by calorimetric method.

Q_k is the heat, carried away from a heat exchanger by a coolant. In specially designed experiments the heating of electrolyte in different zones an electrolytic cell was studied. The temperature of the electrolyte was measured by chromel-alumel thermocouples. The total heat that heats an electrolyte, was calculated as follows:

$$Q'_k = c_e m_e (t_{exit} - t_{end}).$$

Here c_e – an electrolyte heat capacity; m_e – mass flow via a hydraulic pump 10; t_{end} – the temperature at the inlet of an electrolytic cell 3; t_{exit} – outlet temperature after the valves 7 and 8. The experiments

proved the satisfactory agreement of Q'_k and Q_k . This was the criterion of Q_k determination validity, as the heat, removed to the cooling liquid of a heat exchanger. The temperature in the plasma flow was measured by platinum-rhodium thermocouple PR-30/6, which was moved by a coordinate spacer in three mutually perpendicular directions. Throughout the investigated range of currents in a discharge area between the liquid electrolyte anode and cathode the temperature was above the detection limit of a thermocouple. According to indirect estimates the temperature in this area exceed 2000 °C (the samples of ceramics were melted of Al₂O₃).

The mass evaporation rate of an electrolyte was represented by the mass flow of a fresh electrolyte added into an electrolytic cell. The flow rate of the upstream v was estimated by electrolyte consumption through the pump 10 at the closed valve 8.

The current density was calculated as the ratio of current to the surface area of the electrolyte in the discharge binding region to a liquid cathode. The sizes of this zone were determined by video and photographs considering the forcing of an electrolyte under the discharge influence. The depth of the developed indentation was estimated according to the potential measurement within an electrolyte. The photocamera 14 is directed at an angle to the liquid cathode surface, as shown on Fig. 1.

The aqueous solution of sodium chloride in distilled water was used as an electrolyte. During the prolonged burning of the discharge the electrical conductivity of the electrolyte increased, i.e., the

value σ , measured after the experience in the cold condition, was more than original one. Therefore, distilled water was added as a fresh electrolyte. Due to this the growth of σ during the experiment period did not exceed 10%. Hereinafter the thing will be about the values of σ at the room temperature.

3. STUDY RESULTS AND THEIR DISCUSSION

During the discharge burning the flame is yellow one. This color is caused by the emission of sodium atoms that fall from an electrolyte into the discharge region. As can be seen from the pictures, the flames travel along the surface of the electrolyte at low currents (the lower frame, Fig. 2). During the current increase it was deflected upward (middle frame, Fig. 2), at that its height was increased. The further current increase led to the formation of the vertical flame, the length of which reached up to 15-20 cm (the upper frame, Fig. 2). This flame behavior is related to the electrolyte surface geometric shape change in a discharge zone. Under the influence of an electrolyte discharge the electrolyte surface deformed. It sagged inside and an indentation was formed. At the current increase the electrolyte was pressed through stronger. Thus, at large currents the electrolyte evaporation occurred from a concave surface. For this reason, a cumulative effect occurred and the plasma stream generated from an electrolyte vapor, focused in a vertical direction.

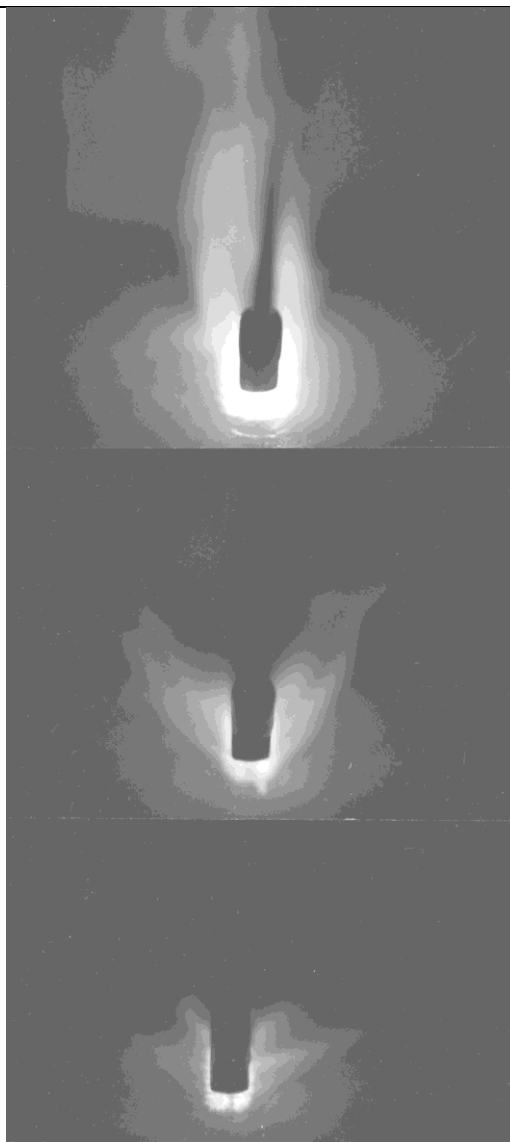


Fig. (2). – Space orientation of plasma flows

Fig. 3 demonstrates the dependences of Q_k on the current. Solid lines approximate the experimental data by directly proportional dependence on the current. The heating of the liquid cathode is dependent on the flow rate of the electrolyte. At low values of v the heat losses on the cathode were much lower than at high speeds. At first glance, it seems incredible. It seems that the slower electrolyte flows, the more it will be warmed up, and the more heat will be spent. In fact, under these conditions, the temperature of the electrolyte rose higher. However, the Joule heat decreased precisely because of it, as R_e

decreased considerably at t increase. For the same reason, (i.e. because of R_e change) with σ increase the heat losses on the cathode were lesser (point 3, fig. 3). Thus, Q_k is considerably determined by the heat Q_j . It should be noted, that the experimental values of Q_k turned to be less than the calculated values Q_j . The detailed analysis of the corresponding reasons was not carried out in the paper.

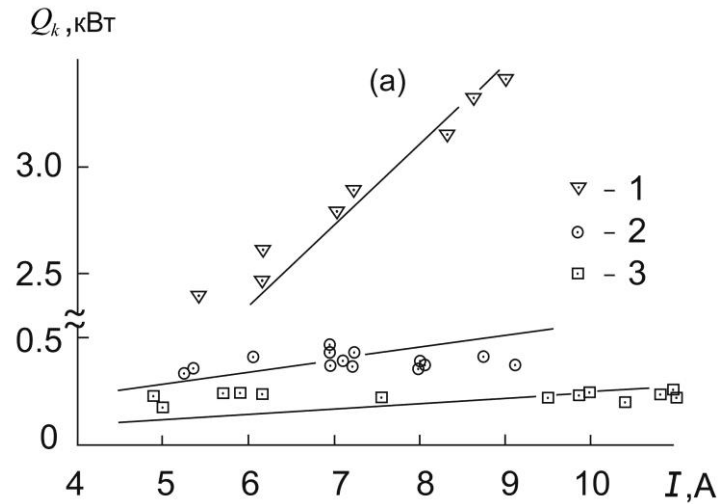


Fig. (3). – Heat losses on cathode

1 - $\nu = 4.5$ cm/s, $\sigma = (0.8 - 1.0) \times 10^{-3} (Om \times cm)^{-1}$; 2 - $\nu = 0.1$, $\sigma = (0.9 - 1.0) \times 10^{-3}$; 3 - $\nu = 0.1$, $\sigma = (2.5 - 2.7) \times 10^{-3}$.

The kinematic parameters of the electrolyte flow and the electrical properties almost did not influence on Q_a . The anode is flowed by the plasma flow and therefore Q_a depends mainly on heat exchange conditions between anode surface and plasma. In the energy balance of the plasma generator the heat loss on the anode make 10 - 20%. The proportion of Q_k was less and was within 5-6 % and less. Thus, the heat efficiency of the plasma generator reached ~ 80 %.

Electrolyte evaporated rapidly under the influence of the thermal discharge. The mass evaporation rate G grew proportionally to the current

(fig. 4). The dependence G on ν and σ was an insignificant one. The influence of these two parameters on G was related probably with the temperature change of the liquid cathode surface layer. At small values of ν it was close to the boiling point of the electrolyte and therefore evaporation occurs from all of free surface of the cathode. With an increase of ν the electrolyte temperature decreases and the evaporation on the open surface (non-occupied by a discharge) of the cathode is weakened. Therefore G decreases. The same thing happens with the σ increase.

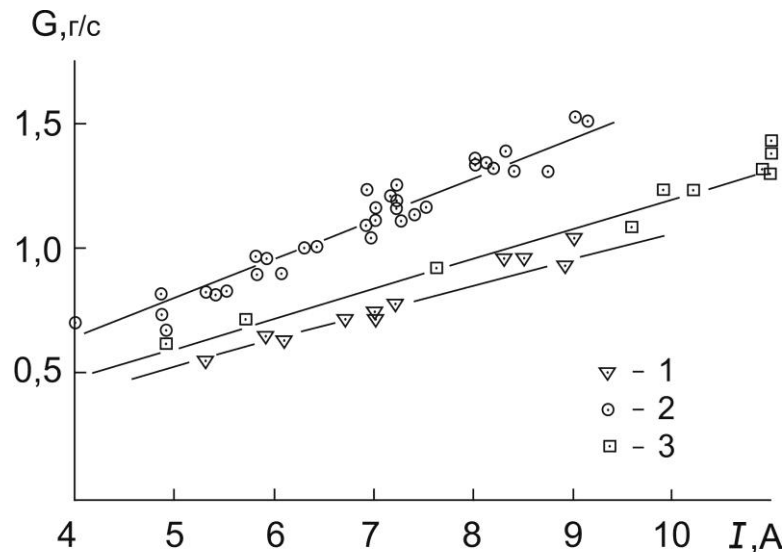


Fig. (4). Mass rate of electrolyte evaporation

The intensity of the heat and mass exchange with the electrolyte is characterized by the current density on the cathode j_k . In the studied plasma generator j_k

changed within the range from 0.8 to 1.0 A/cm^2 . A significant growth of j_k took place within the current interval (4-6) A. At a further current j_k increase it

remained practically constant. It is explained by the fact that the area of discharge linkage to the liquid cathode is

increased at the current increase.

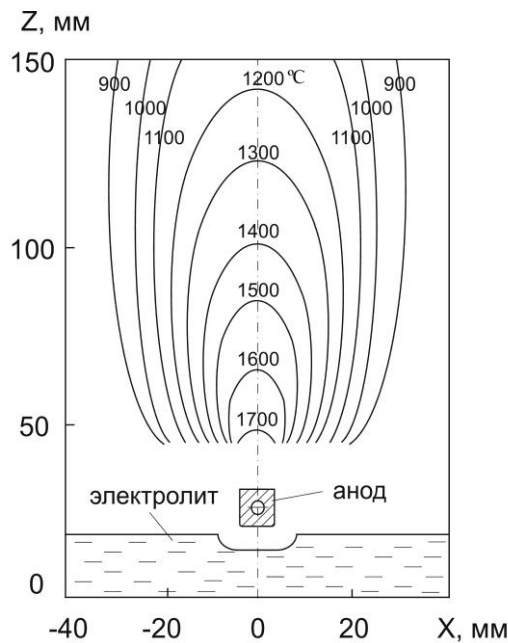


Fig. (5). – Schematic picture of the thermal field at the plasma generator output
 $v = 0.1 \text{ cm/s}$, $I = 11 \text{ A}$, $\sigma = (2.5 - 2.6) \times 10^{-3} \text{ (Ohm} \times \text{cm)}^{-1}$.

The gas heating in the discharge depends on the current density. As in the experiments j_k varied insignificantly, it may be assumed that the gas temperature is essentially constant in the discharge region. It does not exceed a certain maximum value (no less than 2000 °C). The vertical flame temperature was above 1000 °C at the distance of 100 - 150 mm from the discharge zone (Fig. 5). During plasma generator operation, the flame was "playing" continuously. Therefore the isotherms shown on Figure 5 are mainly qualitative ones. At that the error is greater at the top of the flame than at its base.

4. CONCLUSION

The experiments were conducted at extremely high current densities on the electrodes. In these circumstances, the convergence of the liquid cathode and solid-state anode to each other led to the formation of a "hole" in the electrolyte under the influence of a gas discharge. Its depth increased with the current growth. Due to this, first of all, a plasma generator operated stably without ballast resistance; secondly, there was a cumulative effect which contributed to the formation of the plasma flow in a strictly vertical direction. The temperature in the plasma flow remained relatively high (~ 1000 °C) at a considerable distance (100 mm or more) from the anode. The varying the electrolyte flow rate helped to minimize heat losses on the liquid cathode, thereby increasing the thermal efficiency of the plasma generator to 80%.

The plasma generator was tested for the gasification of waste polymer materials. The volatile products of waste polyethylene and polyethylene

terephthalate thermal decomposition were introduced into the plasma stream. Water vapor was used as the transporting gas. The composition of the obtained synthesis gas was analyzed by the chromatograph "Kristall 2000M". Synthesis gas was composed of hydrogen, carbon monoxide and gaseous hydrocarbons. The content of ballast component - carbon dioxide was relatively small. In the case of polyethylene terephthalate waste CO₂ content was somewhat higher and was within 15-25% of vol. Thereby the prospect of liquid electrode plasma generators was determined for the production of a market product - the synthesis gas from the waste materials containing hydrocarbons.

5. SUMMARY

Thus, the experimental studies showed that in the process of waste recycling the plasma generator with the liquid electrolyte cathode is clearly competitive with electric-gas heaters of other types, in particular with arc plasma torches at equal capacities.

CONFLICT OF INTEREST

The author confirms that the presented data do not contain any conflict of interest.

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REFERENCES

- [1] Petrosyan V.S. Dioxins in the environment // Ecology and industry of Russia. 1999. №10. pp. 33-38.

- [2] Bernadiner M.N. Dioxins in the thermal destruction of organic waste // Ecology and industry of Russia. 2000. №2. pp. 13-16.
- [3] Lubina Y.L., Suris A.L. The study of organic solid plasma gasification in a shaft reactor // Thermal Engineering. 1999. №11. pp. 64-67.
- [4] Tumanov Yu. N., Galkin A.F., Solovyov V.B. Plasma pyrolysis of municipal solid waste // Ecology and Industry of Russia. 1999. №2. pp. 8-12.
- [5] Tumanov Yu.N., Galkin A.F., Solovyov V.B. Plasma pyrolysis of municipal solid waste // Ecology and industry of Russia. 1999. №3. pp. 20-25.
- [6] Lozhkyn S.G., Kotlyar E.A. Plasma processing SMW - Russian reality // Solid municipal waste. 2015. №1. pp. 30-31.
- [7] Makunin A.V., Agafonov K.N. Solid waste processing by gasification. // Ecology and industry of Russia. 2004. №3. pp. 34-37.
- [8] A.V. Artemov, Pereslavytsev A.V., Krutyakov Y.A., Voschinin S.A., Kudrinsky A.A., Bulba V.A., Ostry I.I. Plasma technologies for the processing of hydrocarbon raw materials and waste // Ecology and industry of Russia. 2011. №10. pp. 18-23.