Electroplasma processing of medical and biological waste

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Abstract. The article presents an experimental study of biomedical waste in the form of disposable masks. The study was carried out on a laboratory plasma arc installation with a capacity of 20 kg/h. During the experiments, the most important technological parameters were studied: the composition of the exhaust gases, the dependence of the exhaust gases on the temperature in the chamber of the plasma arc furnace, etc.

1. Introduction
Currently, during the coronavirus pandemic, the problem of safely disposing of masks, gowns and other medical waste is most acute. Within the framework of the laws of the Russian Federation N 89-FZ "On production and consumption waste", N 323-FL "On the basics of protecting the health of citizens in the Russian Federation" and sanitary and epidemiological requirements for the organization of the collection, disposal, temporary storage of waste in medical institutions, all medical waste is subject to mandatory disposal, safe for the environment.

To solve this problem, plasma technology is the most optimal technology for safety, productivity, and energy efficiency [1].

To solve the problems of using plasma technology for processing, neutralizing, and destroying hazardous medical waste, it is necessary to carry out a set of tests of an energy-efficient and environmentally friendly electro-plasma installation using an experimental bench to find the best technological parameters, such as the composition of exhaust gases, the dependence of exhaust gases on the temperature in the plasma arc furnace chamber, specific energy consumption during the technological process, etc. The need to obtain these parameters is associated with the further development of a pilot plant with a capacity of 50 kg/h. This work is a novel study, and therefore there are no analogs in the world.

2. Plasma arc furnace
The main equipment in the system of the electro-plasma plant and the technological chain for waste processing is the plasma arc furnace, in the reaction zone of which the temperature level reaches up to 1200-1500°C. Such temperatures can be reached by an electric arc plasmotron with a power of 20-50 kW.

In the course of waste processing, the resulting slag is remelted in the smelting chamber. The plasma arc furnace also provides for slag draining as the chamber is filled with melt.

The technology is based on high-temperature (1200 ÷ 1600 °C) plasma exposure and complete decomposition of high-molecular organic compounds and gasification of utilized products using arc plasma to simple chemical compounds to obtain a useful product – synthesis gas, which is a mixture of hydrogen and carbon monoxide, and also inert slag.
A schematic diagram of an experimental plasma-thermal arc furnace with a capacity of up to 20 kg/h is shown in Figure 1. The plasma arc furnace is designed to develop the technology of high-temperature (plasma) gasification of renewable carbon-containing waste of various origins (sawdust, rags, polyethylene, biomedical waste, etc.).

![Figure 1. Schematic diagram of plasma arc furnace](image)

All biomedical waste (including disposable medical masks) must be packed before disposal. During the experiment, all waste was loaded into lock chamber 2 in a packed form. The sluice chamber, which is also the loading device, is designed to prevent the exit of flue gases from reaction space 3 of the plasma arc furnace, as well as to prevent the ingress of air flows into the chamber. The loading device ensures the correctness of the technological process since the disposal or gasification of waste can take place both under overpressure and with a rarefied atmosphere in the reaction chamber of the plasma arc furnace. The passage of waste through the furnace chamber is provided by a pusher, controlled and monitored by an automatic control system through an oil station by a hydraulic drive 1. Since the plasma arc furnace is a laboratory installation, therefore, in addition to the 50 kW plasmatron 6, a gas burner 5 is installed to quickly reach the operating temperature and warm up the entire furnace lining. After reaching the operating temperature in the interior of the furnace chamber 1200-1400°C, the gas burner is turned off. Since the mass-average temperature of the air plasma jet is 4000K, the subsequent maintenance of the operating temperature of the reaction zone and the process of gasification and waste disposal occurs only due to the plasma torch. The resulting gases in the reaction chamber of the plasma arc furnace in the process of chemical transformations are removed from the chamber and sent to the quenching and gas cleaning system. Carbon and other residues that have not completely entered into chemical reactions, enter the combustion and remelting zone 4. In this section of the furnace, under the impact of a plasma jet, the process of carbon afterburning and remelting of ash residues into vitrified inert slag takes place.

The concentration of \( \text{H}_2, \text{CO, CO}_2, \text{N}_2, \text{O}_2, \text{and CH}_4 \) gases at the outlet of the plasma arc furnace was measured by TEST-1 multicomponent gas analyzer, which is included in the equipment complex.

The analysis of the elemental composition of medical and biological waste, namely, medical masks and disposable syringes, showed that medical masks are made of polymers with wide molecular weight distribution, such as polypropylene, and disposable medical syringes are made of polyvinyl chloride (PVC), which belong to polymeric materials.

To ensure the specified productivity of the electric furnace for waste, it is necessary to know the weight of the package and the speed (frequency) of their feeding into the electric furnace.

Taking into account the mathematical modeling of the high-temperature gasification process of organic waste, the optimal temperature in the reaction zone of the plasma arc furnace (gasification zone) of 1100-1200 °C was selected.
3. Experimental study

Before the beginning of the experimental study, model calculations of the process of utilization of medical and biological waste were carried out. At the same time, the chemical composition of the waste gases and the required weight portion of the waste entering the reaction chamber of the furnace were determined to ensure complete decomposition and destruction of waste. As a result of model calculations, it turned out that the excess part of oxygen reacted with carbon. This led to a decrease in the content of hydrogen in the synthesis gas and an increase in the content of CO and CO$_2$. At the same time, the energy consumption from plasma has significantly decreased from 1.52 to 0.4 kWh/kg.

The calorific value of the resulting synthesis gas practically did not change and amounted to 11.1 MJ/m$^3$. A further increase in oxygen consumption will lead the gasification process to autothermia. The plasmatron will only be needed to stabilize the process and compensate for heat losses.

Analysis of mathematical modeling showed that in the process of gasification of 1 kg of medical wastes, the resulting synthesis gas acquires a calorific value of 11.46 MJ/m$^3$. At the same time, the gas volume of 1 kg reaches 1.54 m$^3$. Using H$_2$O or water vapor as an additional oxidizer increases the calorific value of the fuel gas produced to 11.7 MJ/m$^3$. Taking into account the thermal energy of gas, steam, and molten slag heated to 1500 K, during the gasification of 1 kg of medical wastes, it is possible to obtain 6.86 kWh of thermal energy [2].

Figure 2 shows the experimental results of the gasification of polyethylene granules.

![Graph showing experimental results of gasification](image)

The graph shows that during the gasification of the bulk of the waste, the calorific value of synthesis gas reaches a peak and then gradually decreases. This peak is caused by the fact that, in experimental studies, the waste was fed into the gasification chamber of the plasma arc furnace in portions at regular intervals. To ensure the constancy of the calorific value of the synthesis gas, it is necessary to ensure a continuous supply of waste.

Experimental studies were carried out at two temperature regimes of waste disposal: 800°C and 1200°C.

The first temperature regime of the waste utilization (gasification) technological process, as can be seen from Figure 3, showed not the best result.

4. Experiment results

Analysis of the calculation results of the power distribution of internal heat sources in the cross-section of the furnace, obtained for round, rectangular, and square sections at constant and alternating (single-phase, three-phase) currents, showed that in the upper part of the furnace in the drying zone, the section should be square, while within the rest of the zones it should be round conically diverging.
According to the gas analyzer readings, the exhaust gases contain nitrogen oxides and dioxides, as well as a high content of carbon dioxide. An experiment on the disposal of medical waste at a temperature of 800 °C showed that this temperature is not high enough for the complete decomposition of complex chemical compounds into simple compounds. At a temperature of 800 °C, the elemental composition of the exhaust gases was as follows: CO2-10%, O2-6%, CO-5%, H2-1.5%, and NO-150 ppm. Such a composition of waste gases is not suitable for use in power generating devices, and also has a negative impact on the environment.

After obtaining similar results, in the course of the experiment, the temperature regime was increased to 1200 °C. Having reached the high temperature, the best result was obtained (Fig. 4).

The chemical composition of the gas resulting at a high temperature in the furnace chamber is the best in terms of performance. With an increase in temperature to 1200-1300 °C in the chamber of a
plasma arc furnace, the elemental composition of the exhaust gases was: CO₂-4.5%, O₂-0.5%, CO-22%, H₂-14.5%, NO-0 ppm, and NO₂-0 ppm.

According to experimental data, the composition of the gas does not contain oxides and nitrogen dioxides, and the content of carbon dioxide is also low. The peaks in the graph shown in Figure 4 are due to the discrete feeding of packaged waste.

**Conclusion**

Comparison of calculated and experimental data for the high-temperature gasification process of organic waste show good convergence.

Thus, the goal of the work was achieved, namely, finding the best technological parameters: composition of exhaust gases, the dependence of exhaust gases on the temperature in the plasma arc furnace, specific energy consumption during the technological process, etc. The temperature regimes for the disposal of medical waste before their complete decomposition into simple chemical compounds have been identified. At that, there are no harmful components in the exhaust gas.

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