Automation of plasma technology aimed at the disposal of organic waste

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Abstract. In the article studies are presented for the application of automated plasma electrical technologies in the process of processing and destruction of organic waste. The presented results were obtained in a laboratory experimental plasma electric furnace with a capacity of 20 kg / h. The aspects of ecologically clean gasification of organic waste, the possibility of producing combustible gas and granulated inert slag were set forth. According to the results of the conducted research, the effectiveness of the use of plasma electrical technologies was shown in contrast to the traditional principles of organic waste destruction. The complexity of the automatic control of energy-efficient and environmentally friendly modes of waste gasification and maintenance of the selected mode and the possibility of using simple recurrent neural network in the automation of the technological process were presented.

1. Introduction
Plasma technology is characterized by a wide variety. Thermal low-temperature plasma has found wide application in many technologies. In contrast to traditional chemical processes, plasma-chemical technology is characterized by new effects associated with the electrical conductivity of plasma, its electromagnetic radiation which allows one to apply chemical transformations with high energy efficiency.

The dividing line between definitions of waste is sufficiently conditional, because majority of types of waste must be attributed to carbonaceous. In essence the same types of waste (municipal, medical, agricultural, etc.) are mixed. Their morphological composition is quite complex, and the variable contains organic and inorganic components. Solving the problem of processing (utilization or gasification) of carbon-containing waste, it is necessary to proceed from the fact that it represents a complex of environmental and energy problems with the simultaneous usage of this waste as a constantly renewable energy raw material.

Existing industrial methods for the destruction, neutralization and utilization of carbon-containing waste (landfills, sorting, incineration, biothermal composting, low- and medium-temperature pyrolysis) don’t meet the requirements of environmental legislation. Historically, industrial technologies for the processing of carbon-containing wastes (fluidized bed, incineration) are focused on the use of the principles of one- or two-stage carbon oxidation and they are traditional for thermal energy to produce carbon dioxide CO2 using air as an oxidizer. In these fire technologies, additional fuel (natural gas, coal,
fuel oil) is used to maintain the working temperatures (600−900 °C) that do not allow one to overheat and withstand the gas component of the process for a long time at a guaranteed average temperature of 1300 °C and above. The mineral part of the waste is formed in the type of toxic solid slags and additional environmentally friendly technologies are required for their processing.

When solid municipal waste is burnt, two types of ash are formed: hearth and volatile (dust), and ash is released during flue gas cleaning the process. The bottom ash may contain more than 10% unburnt carbon including hydrocarbons with the inclusion of benzo (a) pyrene and other normalized hydrocarbon-carcinogens. Fly ash contains soot and volatile compounds of heavy metals - oxides, chlorides, sulfates. Precipitation and accumulation of polychlorinated dioxins and furans could be on soot.

For countries where almost 100% of municipal solid waste is burnt, the volumes of both types of ash reach millions of tons and their burial causes new environmental problems. One of the ways to solve the problem is to melt the ash in a plasma furnace with the production of chemically inert slag, non-toxic gas emissions and a small fraction (8 ... 15% by mass) of secondary dust with a high content of harmful impurities.

The most typical type of toxic waste is a medical one which is characterized primarily by the presence of toxins (toxic proteins, metabolic products of microorganisms) and general infection, they can cause disease and death of people and animals. Thus, during the process of recycling medical waste it is necessary to solve the problem of the destruction of toxicity, which can be done by plasma methods with complete oxidation of carbon-containing components. It causes decomposition and oxidation of chemicals contained in the waste with simultaneous long exposure at high temperature of the infected part of the original product. Therefore, the main task of this technology is the environmental problem of waste disposal with the minimization of material costs.

The analysis of modern methods for processing carbon-containing waste shows that for the last time technological aspects are being shifted towards a significant increase in temperature in the reaction zone as compared with the known incineration plants (plasma technologies). At the same time, there is a functional separation of the processes at the stage, for example, of gasification of the organic part of the waste with the production of synthesis gas and its subsequent combustion in power boilers or its use as a valuable product in chemical production.

The new electrical technologies include an environmentally friendly plasma gasification technology for waste allowing for the deep decomposition of all compounds to form simple substances and to convert all non-pyrolysable (inorganic) residues into liquid slag, conduct high-temperature pyrolysis (≤1200°C) and produce synthesis gas with a calorific value of 10−13 MJ / nm³.

One of the most important advantages that plasma (high-temperature) technologies bring to a fundamentally different class of processes in terms of environmental friendliness and efficiency is the oxidation of carbon to CO monoxide and the elimination of ballast nitrogen from the production cycle. These factors reduce the amount of waste gases more than 5 times by weight and 3 times by volume. It allows one to clean effectively the resulting synthesis gas and the slag contains almost no oxidized substances and is not contaminated with dioxins and furans. The relatively low mass of synthesis gas allows the gas to be quenched in vortex scrubbers (centrifugal-bubble apparatus) with an alkaline solution. This operation fundamentally prevents the formation of toxic compounds (dioxins, nitrogen oxides, sulfur compounds, chlorine, etc.). This technical solution guarantees the fulfillment of environmental requirements for modern industrial technologies without the use of multistage, complex and expensive gas cleaning systems.

Waste treatment technologies can be carried out in weakly oxidizing and reducing atmospheres and have two zones separated in space: medium temperature (t ≥ 1000 °C) for drying, pyrolysis and gasification, and high temperature (t ≥ 1300 °C) to complete gasification processes, melting the inorganic part of the waste and heating gaseous product (synthesis gas) to the optimum temperature.

First of all, the high-temperature zone should ensure the effective heating of the synthesis gas to a mass-average temperature of t ≥ 1200 °C. This technological stage is crucial for optimizing performance, cost and environmental performance of implemented technical solutions. Besides, solid residue is
melted, melt accumulated, slag and metal are periodic or continuous discharge in this zone. Slag-metal mixtures obtained as an additional product have inert properties and can be used for road construction, production of foamed granules, slag wool, and molded general-purpose slag products. An increase in the residence time of the processed raw materials in each working temperature zone makes it possible from the new positions to substantiate the values of the required temperatures by zones, to ensure consistent temperature-technological connection of these zones with the active use of plasma flows and the surface of molten slags and metal as heating units. Finally, the well-known principles of hydrogen energy has been implemented in plasma technologies, which make it possible to reduce the specific volume of carbon dioxide emitted into the atmosphere when syngas is burned (by 1 kWh of energy produced).

The main complexity of the automatic control of energy-efficient and environmentally friendly modes of waste gasification and maintenance of the selected mode is the coordination of many parameters. Among such parameters are the level of discharge in the chamber of an electric plasma furnace, the temperature in the chamber and the outgoing syngas gas, the composition of synthesis gas, the power of the plasma torch, etc.

2. Description of the laboratory plasma electric furnace

The outlined concept of high-temperature (plasma) technology is confirmed by computational and experimental studies. Experimental studies on plasma gasification of carbon-containing wastes were carried out on a laboratory electric furnace with a water-deposited metal casing. A visual representation of the main elements of a laboratory plasma electric furnace is given in Fig.1.

The plasma electric furnace is equipped with air plasma torch 6 with an adjustable power from 25 to 50 kW. To regulate the power of the plasma torch, the ballast resistance Rb from 1 to 10 ohms is used in the form of a “tube in tube” water rheostat. A change in the position of the rheostat occurs by applying a control signal of 4 ... 20 mA from the automation system to the controlled mechanism for moving the rod of the rheostat. Measurements of the current and voltage of the arc discharge are carried out by means of receiving signals from thermocouple sensors, which are fed to the analog inputs of the controller converted by normalizing converters into a 4..20 mA signal. Maintaining the optimum temperature in the reaction zone of the electric furnace for the process of waste gasification is carried out by changing the power of the plasma torch control signal from the controller from the PID controller. A plasma torch was used with a two-chamber scheme and the plasma jet was directed at an angle to the surface of the molten slag bath. Waste was fed through the loading device 2 in the upper part of the furnace. For the operation of the boot device, responsible automatic control cabinet is connected to a common network of industrial controllers. Further promotion of waste through the reaction chamber of
the furnace is carried out by the pusher 1. Thermocouples are installed flush with the lining on the working space of the furnace to monitor the dynamics of temperature change. Concentrations of \( \text{H}_2, \text{CO}, \text{CO}_2, \text{NO}_x, \text{SO}_2 \) in the gas path were measured by a gas analyzer of the “Test-1” type. The controlling controller receives digital signals from the gas analyzer on the composition of the synthesis gas. The automatic system, according to the technological process, issues control signals to the loading device, the pusher and the smoke exhausters. The synthesis gas in the furnace from the reaction zone with a temperature of 1200 °C enters the centrifugal apparatus where it makes contact with cold alkaline solution and is subjected to quenching and cleaning. Next the hardened synthesis gas is fed by the fan into the afterburner chamber. After this the combustion products are vented to the atmosphere through ventilation. The resulting molten slag is poured into a water bath where it is cooled and granulated. The granulated slag is similar in shape to construction rubble with fractions up to several millimeters, dark in color with high resistance to dissolution in water and in weak acids. According to current standards it is suitable for the production of concrete, road construction, etc.

3. Research results of the laboratory electric furnace

When conducting experimental studies, the model waste has been loaded in the furnace of different composition. The moisture content for model wastes was varied within 20 ... 60% by weight. Therefore, the effect of humidity on specific energy consumption is of practical interest.

![Figure 2](image)

**Figure 2.** The dependence of the specific energy consumption for pyrolysis of 1 kg of waste from their moisture: 1 - consumption of plasma-forming air is absent; 2 - air consumption is 0.15 g / s per 1 kg of waste per hour; points – experiment

It is seen that when the energy source is an air plasma jet, the energy consumption becomes much less (mode 2) due to the energy of chemical reactions of oxidation of carbon with oxygen in the air. The existing discrepancy between the calculation results and experiments is mainly due to the fact that the calculation did not take into account heat losses in the furnace and the walls of the electric furnace.

Analysis of the data (shown in Fig. 2) shows that in the range of changes in humidity within 20 ... 50%, specific energy consumption ranges from 0.4 to 0.75 kWh / kg, while the calculated data are located below, at the level of 0.3 ... 0.5 kWh / kg The discrepancy between the results is due to the neglect of the losses, as already mentioned, as well as errors in the measurements of the mass of the loaded waste and its moisture. Experimental data obtained clearly indicate that in order to save electricity, waste requires pre-drying. Calculations show that waste, even at a minimum humidity of 20%, contains all the chemical elements necessary for complete gasification.

A positive factor in the additional supply of plasma-forming air is the ability to use the same plasma electric furnace for various purposes only by control of the gas flow rate and the power of the plasma.
torch for various purposes: either for the production of synthesis gas or for the destruction (burning) of waste. Besides, the furnace is suitable for both separate and joint processing of household, industrial, medical, agricultural and other carbon-containing wastes. For any temperature level in the reaction zone, the ratio of the synthesis gas components is established. From the results of laboratory electroplasma research, it follows that the specific energy consumption for processing / destruction of 1 kg of waste, depending on air consumption, humidity and morphological composition, varies between 0.1 ... 0.75 kWh /kg. In experiments on gasification and waste incineration, the high reliability of flue gas cleaning ecological block system is shown. This system consists of a vortex alkaline solution scrubber and a syngas combustion chamber. Control measurements found that the main parameters of flue gases did not exceed the existing world standards for MACs.

4. Conclusion
Due to the high temperature in the reaction zone, the necessary deep decomposition of waste takes place with the formation of simple compounds, which greatly simplifies their purification from harmful impurities. The use of plasma technology significantly (3 ... 5 times) reduces the volume of produced gases in comparison with the burning technology of waste, ensures their effective cleaning and thus eliminates the release of toxic substances into the atmosphere. Thermal decomposition of dioxins begins at 750 °C and up to 1200 °C is reversible. Plasma gasification of organic waste makes it possible to withstand synthesis gas at t ≥ 1300 °C for 2–3 s and gives an irreversible decomposition of high molecular weight of organic carbon compounds. Foamed or granulated slag has inert properties, is not eroded by water and can be used as a building material.

Further studies are aimed at determining the energy-efficient and environmentally friendly modes of gasification of carbon-containing wastes, independent of their morphological composition. When solving a multiparameter problem, modern machine learning algorithms will be used based on the use of a simple recurrent neural network with memorization of the sequence of actions of previous states, allowing network training and adjustment of parameters in the on-line mode.

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References
[1] Messerle V E, Ustimenko A B, Lavrichshev O A, 2014 Proceedings of the ASME gas turbine India Conf. vol. 001(03) A003
[2] Aliferov A I, Anshakov A S, Sinicin V A, Domarov P V, Danilenko A A 2016 Journal of Phys.: Conf. Series 754 112002
[3] Zhukov M F, Timoshevskiy A N, Cherepanov A N 1997 T and A 4 (2) 227-237
[4] MesserleV E, Mosse A L, Ustimenko A B 2018 Waste management 79 791–799
[5] Golish V I, Karpenko E I, Luk’yashchenko V G, MesserleV E, Ustimenko A B, Ushanov V Zh 2009 High energy chemistr u 43 (4) 318-323
[6] MesserleV E, Mosse A L 2017 T and A 24(4) 605-614
[7] MesserleV E, Mosse A L, Ustimenko A B 2016 T and A 23(4) 613-620
[8] MesserleV E, Ustimenko A B, Lavrichshev O A Fuel 203 887-883
[9] Anshakov A S, Faleev V A, Danilenko A A et al. 2007 T and A 4 607-616
[10] Park H S, Lukashov V P, Vashchenko S P, Morozov S V 2009 T and A 16(4) 611-620