Experimental studies of plasma-thermal waste disposal

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Abstract. The paper presents the results of computational and experimental studies of plasma gasification of technogenic carbon-containing waste in order to obtain flammable (high-calorie) synthesis gas (H2+CO) for energy-generating devices. Experimental results of the fuel composition obtained in the process of gasification of organic waste are presented. The change in the composition of fuel gas depending on the time of gasification of organic waste was studied.

1 Introduction

In the modern world, one of the global trends in technology development is the constant increase in the efficiency and environmental friendliness of methods for managing carbon-containing waste. Carbon-containing industrial wastes include: household (municipal solid waste (MSW)), agricultural (rice husks, etc.), industrial (wood waste, coal sludge, etc.) and biological (medical, biological sludge (BIS), etc. d.)

Despite the different nature of these wastes, they all consist of the same chemical elements: carbon, hydrogen, oxygen, nitrogen, chlorine, sulfur, ash (a complex of inorganic elements and compounds), water (moisture), but they contain elements and compounds. hazardous to the environment (pathogens, heavy metals, etc.).

The impact of carbon-containing waste on the environment is varied. This waste has a significant negative impact on the environment: soil, water, atmosphere and biosphere.

As shown by the results of the analysis of modern scientific, technical and patent documentation, plasma technologies for processing carbon-containing waste to produce synthesis gas (fuel gas) with its further use in energy-generating devices are being actively developed.

The optimal technology for safety, performance and energy efficiency is plasma technology. The technology is based on high-temperature (1200÷1600 °C) plasma exposure and the complete decomposition of high-molecular organic compounds and gasification of recycled 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.

Gasification of carbon-containing (organic) materials can be simplistically described by basic chemical reactions (Table 1).

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Table 1. Heat treatment reactions of solid waste.

№	Reactions	Thermal effect		
		кДж/кМ	кДж/кг	кДж/м^3
1.	$C+O_2=CO_2$	395 000	32 890	-
2.	$2C+O_2=2CO$	110 000	9 600	-
3.	$C+CO_2=2CO$	–175 500	–14 610	-
4.	$C+H_2O=CO+H_2$	–130 500	–10 860	-
5.	$C+2H_2O=CO_2+2H_2$	–132 000	–10 990	-
6.	$C+2H_2=CH_4$	–74 900	–6 240	-
7.	$2CO+O_2=2CO_2$	285 600	-	12 750
8.	$2H_2+O_2=2H_2O$ (liquid)	286 200	-	12 780
9.	$2H_2+O_2=2H_2O$ (vapor)	241 800	-	10 760
10.	$CH_4+2O_2=CO_2+2H_2O$ (vapor)	801 920	-	35 800
11.	$CO+H_2O=CO_2+H_2$	40 400	-	1 800
12.	$C_2H_4+3O_2=2CO_2+2H_2O$	1 322 500	-	59 040
13.	$2H_2S+3O_2=2H_2O+2SO_2$	518 110	-	23 130

Each reaction occurs in its own temperature range. In the steady-state operating mode of the electric furnace, in its working space there are stationary temperature distributions of moving waste and gas flow over height. This determines the distribution of the energy effects of chemical reactions along the height of the furnace.

The reaction occurs in the presence of reagents in the reaction space at a temperature above equilibrium. When waste is heated sequentially, it undergoes decomposition with the release of various gaseous substances that will take part in oxidation reactions (Table 1). The simulation results are presented in Figure 1.

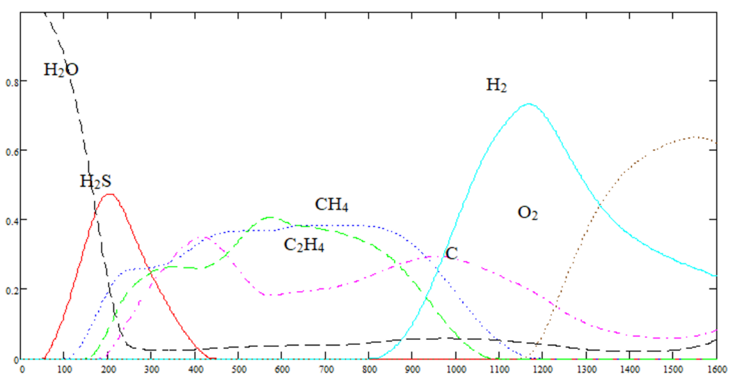

Fig. 1. Composition of gases released from waste at different temperatures.

Thus, we can obtain specific values of the masses of gases participating in the reactions for any elementary volume of the working space of a plasma electric furnace, knowing the temperature distribution along its height, for a given productivity of an electroplasma installation for waste processing.

2 Description of the experimental setup

The work was carried out on an experimental installation with a capacity of up to 20 kg/h for gasification of solid organic waste [1]. The schematic diagram of the plasma-thermal installation is shown in Figure 1. The internal chamber of the electric furnace has two interconnected lined chambers. Portions of processed material packed in cardboard were fed into the reaction chamber of the electric furnace through a loading device. The heating of the working chamber of the plasma electric furnace and the lining was carried out by an electric arc air plasma torch with a power of up to 50 kW. The synthesis gas released in the gasification zone was taken from the furnace chamber (the process is indicated by an arrow in Figure 2) into the cleaning unit of a centrifugal bubbling apparatus (CBA) 1 with an alkaline solution, in parallel - to a multicomponent gas analyzer 3 of the "TEST-1" type. The volume percentage of gas components was determined using a gas analyzer in real time. Measurements of temperature T and determination of gas composition were carried out along the gas path (3 in Fig. 1). The ash residue formed during the processing of these wastes is melted into inert slag under the influence of a plasma jet at a temperature of 4000 K. In addition to the above equipment, the installation included: a power supply for plasmatron 4, a control panel for it, a gas and water supply system, a gas analyzer, thermocouples, a supply and exhaust ventilation system, a waste supply control panel, a gas afterburner 2, and a flue gas cooler.

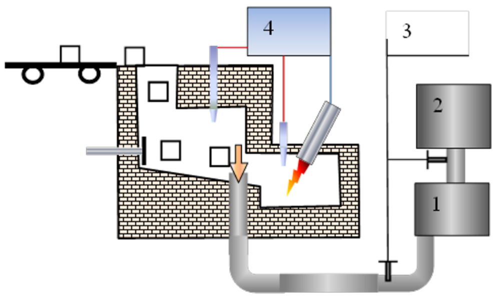

Fig. 2. Diagram of an electroplasma installation. 1 - CBA cleaning unit, 2 - gas afterburner, 3 - gas analyzer, 4 - plasmatron.

3 Experimental studies

Before carrying out the main waste disposal process, the electric plasma furnace was initially heated to the required temperature in the working chamber to ensure the correct technological process. After the temperature in the gasification zone reaches 1100-1300°C, the supply of waste packages to the oven begins.

The residence time of the waste is determined depending on the initial composition of the waste and productivity. For example, packages with waste weighing 1 kg pass through the gasification zone in 3 minutes, i.e. In 1 hour, 20 packages are supplied for gasification, ensuring an electric furnace productivity of 20 kg/h. This residence time of the waste in the reaction chamber allows the complex chemical components of the waste to be completely decomposed into simple compounds in the form of gas.

Model waste, packaged in boxes, is fed into the working chamber of the electric furnace through a loading device. Also, the loading device functions as a lock chamber, preventing atmospheric air from entering the gasification chamber and flue gases from escaping into the atmosphere from the chamber when excess pressure appears during waste processing.

The fuel gas (synthesis gas) released in the gasification zone is taken from the furnace chamber. It is fed into a centrifugal bubble apparatus (CBA), where it is mixed with a water flow, forming a liquid-bubble mixture for its further hardening and cleaning of the dust contained in it. The liquid is an aqueous-alkaline solution. Flue gas purification from solid particles is 96-98%, from chlorine and sulfur – about 80%. Before the CBA, gas is sampled with a gas analyzer, carrying out analytical control of the composition of the resulting synthesis gas. A built-in thermocouple in the chimney in front of the central pump monitors the temperature of the extracted fuel gas. After passing through the CBA, the synthesis gas is supplied to the afterburner, where it burns to CO2. The volumetric flow rate of humidified flue gases at the exit from the central combustion unit (at the inlet to the afterburner) is 100-110 nm^3/h. The temperature in the afterburner chamber from the gas burner is 1200 °C.

From the afterburner, flue gases are discharged into a cooler (t ≤ 200 °C) for subsequent purification in filters and release into the atmosphere. To cool the flue gases, the required amount of atmospheric air, controlled by an automatic control system, enters the mixer. The control signal is generated depending on the required temperature of the flue gases emitted into the atmosphere.

Taking into account mathematical modeling of the process of high-temperature gasification of organic waste, the optimal temperature in the reaction zone of the electric furnace (gasification zone) was chosen to be 1100 – 1200 ºC.[3].

4 Experimental results

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

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

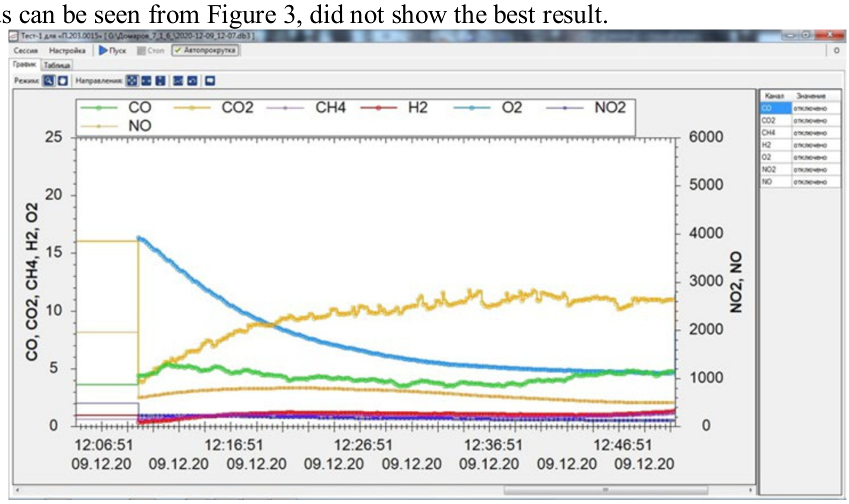

Fig. 3. Gas analyzer readings at a temperature of 800°C.

According to the gas analyzer, the exhaust gases contain nitrogen oxides and dioxides, as well as a high content of carbon dioxide. At a temperature of 800 °C, the elemental composition of the exhaust gases was: CO2-10%, O2-6%, CO-5%, H2-1.5%, NO-150 ppm.

This composition of exhaust gases is not suitable for use in energy generating devices, and also has a negative impact on the environment.

After obtaining similar results, during the experiment the temperature was increased to 1200 °C. Having reached a high temperature level, we got the best result (Fig. 4).

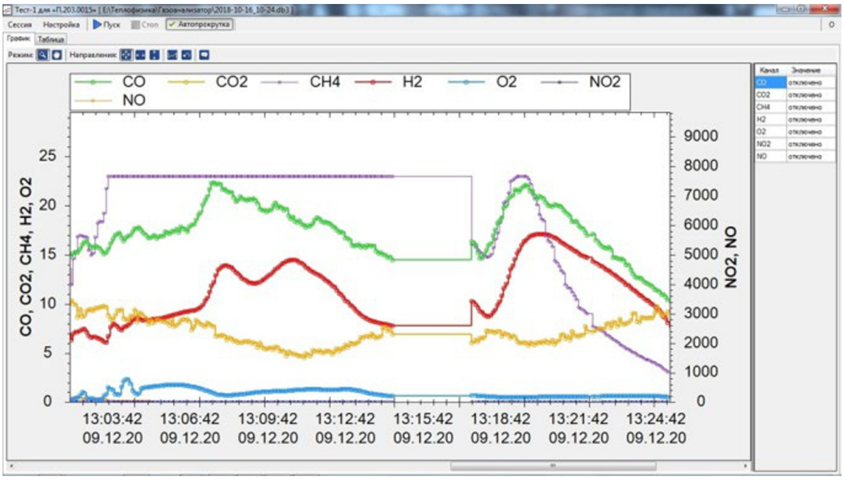

Fig. 4. Gas analyzer readings at a temperature of 1200 °C.

The chemical composition of the resulting gas at high temperatures in the furnace chamber has the best performance. When the temperature increased to 1200-1300 °C in the plasma electric furnace chamber, the elemental composition of the exhaust gases was: CO2-4.5%, O2-0.5%, CO-22%, H2-14.5%, NO-0 ppm, NO2-0 ppm.

According to experimental data, the gas composition does not contain nitrogen oxides and dioxides, and also has a low content of carbon dioxide.

During gasification of the bulk of materials, peaks in the calorific value of synthesis gas and other gases are observed, then a gradual decrease occurs, similar to those given in [1]. These peaks are caused by the fact that during experimental studies, waste was fed into the gasification chamber of a plasma electric furnace in portions after certain periods of time. To ensure a constant caloric content of the synthesis gas, it is necessary to ensure a continuous supply of waste at certain intervals.

5 Conclusion

Specific energy consumption for the production of synthesis gas ranges from 0.48 kWh/kg to 2.2 kWh/kg, depending on the initial composition of the waste. The caloric content of the resulting synthesis gas ranges from 8 to 13 MJ/kg, which allows it to be used for combustion in power generating units.

A preliminary thermodynamic calculation of the plasma gasification of organic waste, which was used in experimental studies on a laboratory electroplasma installation with a capacity of 20 kg/hour, showed the possibility of producing synthesis gas.

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

Thus, the goal of the work was achieved - finding the best technological parameters: the composition of the exhaust gases, the dependence of the exhaust gases on the temperature in the chamber of the plasma electric furnace.

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