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Features plasma gasification of organic waste

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Abstract. The paper describes the main results of mathematical and experimental studies in the process of gasification of organic waste in a plasma electric furnace. In the course of research, work was carried out to study the reduction of energy consumption during waste gasification. Studies were also carried out on the effect of reducing energy consumption during waste gasification, excluding the inorganic component of waste. The article presents the results of computational and experimental studies of the gasification of organic waste and the effect of the inorganic part on the energy balance of an electric plasma furnace.

1. Introduction

Worldwide, there is a catastrophic increase in waste of various types. In European countries, from 300 to 750 kg of municipal waste and from 1000 to 2500 kg of industrial waste are generated per inhabitant annually [1].

Annually, increasing volumes of waste around the world are pushing to search for particularly efficient methods for their recycling. The open landfills and dirt fills, which contaminate the environmental, are replaced by the thermal processing methods: incineration; pyrolysis; gasification.

Incineration is one of the main methods of waste disposal in the modern world, as they contain a large amount of fossil fuels. Since the process of waste burning occurs at the temperature of 800 - 850°C, the exhaust gases contain toxic substances (dioxins, furans), high-molecular toxic compounds, etc.

In the modern world, one of the global trends in technology development is the continuous increase in the efficiency and environmental friendliness of organic waste management methods. The study of the gasification of organic waste (OW) is associated with the need to solve a number of tasks: to make toxic organic compounds safe by decomposing them into simple components, to use the energy potential of the waste, to reduce energy consumption for their processing.

Despite the different nature of this waste, they all consist of the same chemical elements: carbon, hydrogen, oxygen, nitrogen, chlorine, sulfur, ash (a complex of inorganic elements and compounds), water (moisture), and contain elements and compounds dangerous for the environment (pathogens, heavy metals, etc.). The significant negative impact of organic waste on the environment (soil, water, atmosphere, biosphere) is diverse.

As the results of the analysis of modern scientific and technical [2-5] and patent documentation show, plasma technologies are being actively developed for the processing of OW with the production of synthesis gas (fuel gas), using it later on in power generating devices.

Gasification of OW is a complex physico-chemical process with a large number of effects. The



composition of OW can vary in a wide range, which requires the creation of a flexible and universal technology.

Currently, waste recycling/disposal by plasma technology is one of the safest methods. Worldwide, there are only a few small plants that test plasma technology, the main drawback of this technology is the low lifetime of plasmatron electrodes (up to 100-300 hours). In Russia, plasma installations for waste disposal are not used, but there are single experimental plasma installations for processing waste of various hazard degrees.

Currently, waste gasification technologies are shifting to high temperatures exceeding 1500 °C. This condition is well matched to plasma electrical technologies, one of the drawbacks of which is high energy intensity (up to 1 MW per 1 ton of waste) [6-8]. Therefore, the study of plasma gasification processes in electrical installations with a decrease in energy consumption for the tasks of OW processing is in great demand at the present time.

It is known that in the composition of OW, along with the organic component, the inorganic part is also present (glass, ceramics, metals, etc.). Depending on the region, the percentage of inorganic content varies. The inorganic part of the waste absorbs energy for heating and remelting.

To reduce energy consumption in the process of OW gasification, theoretical and experimental studies were carried out. The options for energy consumption during gasification of the full SMW morphological composition (organic and inorganic components) as well as the option excluding the inorganic part of waste have been considered. The second option is similar to the process of waste gasification with pre-sorting, excluding penetration of the inorganic component into the further energy balance.

2. Calculation of energy gasification

To estimate the total energy and power spent for gasification of organic waste, it is necessary to know the amount of heat spent for waste heating until organic part decomposition and processing.

For example, let us draw up the energy balance of the working space of the plasma electric furnace. The energy balance is an equation consisting of supplied and waste heat. When making the energy balance, the type of fuel (morphological composition of waste) and performance are considered the given parameters.

During plasma wastes gasification in the working space of the furnace, energy is released and absorbed in chemical reactions, energy is supplied to the furnace shaft from a plasma jet in the combustion zone. The removed heat includes: heat of liquid slag, power of heat loss through the lining and/or water-cooled housing, heat removed with the synthesis gas, and absorbed energy of endothermic reactions.

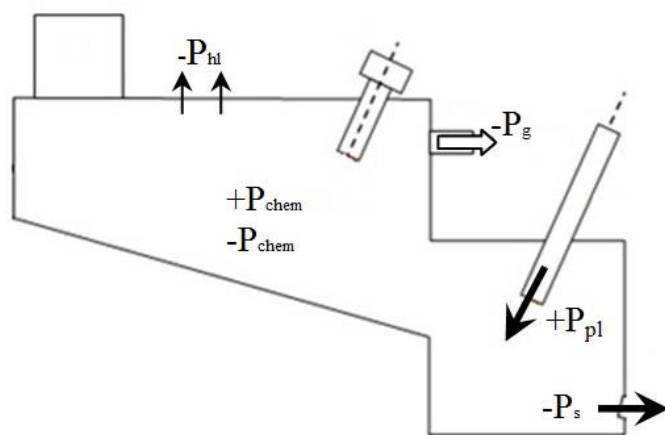


Figure 1. Scheme of the energy balance of the plasma electric furnace.

The diagram (Figure 1) presents the main items of energy income and consumption. Power, entering the working zone of the furnace, is indicated with the “+” sign, and the consumed and waste power is indicated with the “-” sign.

According to the scheme (Figure 1), the energy balance equation takes the form of:

$$P_{e.m.} + P_t + P_{pl} + P_{chem} = P_{hl} + P_s + P_{sg} + P_h \quad (1)$$

where $P_{e.m.}$ – power introduced into the furnace shaft by ohmic heating; P_t – power coming with heated waste, since calculations are performed under the assumption that the waste is not pre-dried and heated, then $P_m = 0$; $P_{chem} = P_{ek} + P_{en}$ – power released during chemical reactions in the process of waste gasification: P_{en} – power of exothermic reactions, P_{ek} – absorbed power of endothermic reactions; P_{pl} – plasmatron power; P_{hl} – power of heat losses through the lining; P_s – power of losses with slag; P_{sg} – power of losses with synthesis gas; P_h – heat spent for waste heating.

$$P_h = \sum_{i=1}^n Q_{hi}, \quad (2)$$

where $Q_{hi} = m_i C_{pi} \Delta T$, m_i – number of substance moles in waste composition; C_{pi} – average specific heat capacity of the i -th component of waste [J/mole·degr]; ΔT – heating range °C.

3. Experimental studies

The scheme of an electric plasma installation, where the experimental studies on waste gasification in the air-plasma environment were carried out, is shown in figure 2. The plant capacity is 20 kg/h for the technological process of plasma utilization of renewable carbon-containing waste of both separate (sawdust, rags, and polyethylene) and mixed types. The main task of the plasma-thermal electric furnace is to increase the environmental and economic efficiency of OW processing.

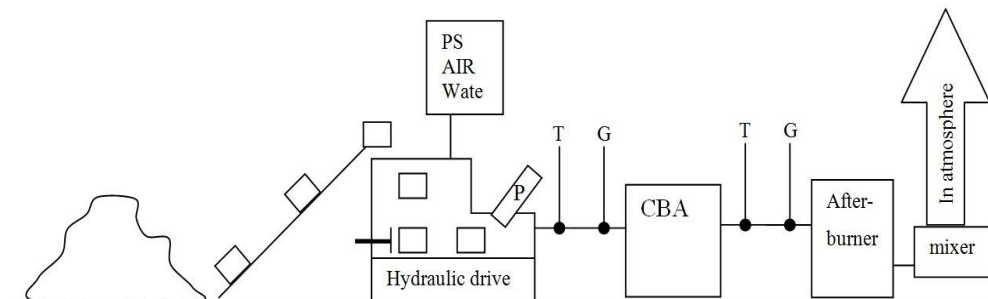


Figure 2. Scheme of electric plasma installation.

The process of solid waste recycling in a plasma-thermal electric furnace is as follows. Model wastes, packed in boxes, are fed into the working chamber of an electric furnace through a loading device. The loading device performs also the function of a lock chamber, preventing penetration of atmospheric air into the gasification chamber and exit of flue gases from the chamber into the atmosphere, when excess pressure appears during waste processing.

Further movement of the packaged waste to the gasification zone occurs by a hydraulic pusher connected to the oil station. A feeder is also connected to it. The oil station and pressure in the system of hydraulic actuators are controlled by an automatic system based on an industrial controller.

The working chamber of the plasma electric furnace and lining are heated by an electric arc plasmatron with a power of 50 kW and gas burner up to 1200 °C; later it is turned off. The temperature in the chamber is controlled by a thermocouple and a signal is sent to the ACS through a normalizing converter. When the operating temperature in the furnace chamber reaches 1200 °C, a control signal is sent from the controller to the power source to further reduction of the plasmatron power in order to maintain the temperature and melt the inorganic waste residue.

The fuel gas (synthesis gas) released in the gasification zone is removed from the furnace chamber. It is fed to the centrifugal-bubbling apparatus (CBA) for its further quenching in gasification reactions and cleaning of dust contained there. Before the CBA, gas is sampled by a gas analyzer, carrying out

analytical control of the composition of the synthesis gas produced. The temperature of the sampled fuel gas is monitored by the thermocouple built-in into the chimney in front of the CBA. After passing through the CBA, synthesis gas is fed to the afterburner, where it burns to CO₂. To cool the flue gases, the required amount of atmospheric air, controlled by the automatic control system, is fed to the mixer. The control signal is formed depending on the desired temperature of the flue gases emitted into the atmosphere.

The ash residue formed during the processing of model wastes under the influence of a plasma jet with a temperature of 4000K is melted into inert slag. As the bath of liquid melt is filled, the slag is periodically poured out through a tap hole into a sliding carriage.

4. Results of investigations

In the working chamber of an electric furnace, 91.5 kWh of energy is released during chemical reactions. Let us calculate the amount of heat required to heat 100 kg of fuel and 54 kg of air additionally fed to the reactor. Fuel contains: C, H₂, O₂, H₂O, and inorganic components. Air contains O₂ and N₂. The general formula for determining the energy, required for heating, is:

$$Q_o = \sum_{i=1}^n Q_i. \quad (3)$$

That is, the total amount of heat (energy) is determined by the sum of separate amounts of heat required for heating the separate components of material, $Q_i = m_i C_{p_i} \Delta T$, where m_i – mass of the i -th component of substance, C_{p_i} – specific (average within the temperature range) heat capacity at a constant pressure.

$Q_o = 154.6 \text{ kW} \cdot \text{h}$ – the total amount of energy required for heating 100 kg of fuel and 54 kg of air.

The efficiency of electric furnace is about 90%. Hence, the actual energy demand will be not 154.6 kW·h, but $154.6 \cdot 100 / 90 = 171.1 \text{ kW} \cdot \text{h}$. Among them, 154.6 will be spent on heating the fuel and air, and 16.5 kW·h will be dispersed into the atmosphere through the lining and housing or removed by water in the cooling case. Consequently, the total power of all heat sources, providing heating to 1200°C, should be 171.1 kW. Chemical reactions provide the power of 91.5 kW. Using equation (1), we get:

$$P_{pl} = P_{chem} - P_{hl} - P_s - P_{sg} - P_h = 98.95 \text{ kW}, \quad (4)$$

where P_{chem} – the calorific value (total) of 100 kg of fuel $15000[\text{kJ/kg}] \cdot 100[\text{kg}] = 416[\text{kW} \cdot \text{h}]$; P_{sg} – physical heat of synthesis gas – 154.6 kW·h; P_s – physical heat of ash – 5.55 kW·h; P_{hl} – heat cooling water of the plasma torch and reactor – 35.85 kW·h; P_h is heat spent on waste heating – 171.1 kW·h.

The gasifier receives 100 kg of fuel with a calorific value of 15,000 kJ/kg per an hour, and plasmatron operates with a capacity of 98.95 kW and 79.6 kW of them represent the useful power. Synthesis gas leaves the gasifier, carrying away 154.6 kW·h of physical heat, and taking into account the efficiency of the gasifier, 171.1 kW·h of physical heat is lost.

In accordance with the above calculations, 0.98 kW of energy should be spent for 1 kg of OW. The inorganic part of OW composition in the process of waste gasification takes about 0.09 kW of energy per 1 kg for heating and melting. When the inorganic part is excluded from the waste, energy consumption is reduced by 9 kW at the electric furnace capacity of 100 kg/h.

In a long-term (in time) technological process of OW gasification, there is a significant energy saving. With a decrease in the power of plasmatron, there is an increase in the resource characteristics of electrode operation.

5. Conclusion

After conducting numerical and experimental studies, we can draw the following conclusions:

- to ensure more efficient processing and gasification of waste, it is advisable to combine two technological processes: sorting and plasma gasification of waste;
- the sorting process allows you to select recyclable materials from the waste (metal, glass, plastic);

- the pre-screening process also reduces energy consumption for the gasification of organic waste.

According to the results of research, it was obtained that for 1 kg of textile waste, depending on the oxidizing gas (air, steam, oxygen), the release of combustible gas with a volume of 1.22 to 1.5 nm³ and a calorific value of 9 to 11.5 MJ / nm³ is obtained. For 1 kg of sawdust, depending on the oxidizing gas (air, steam, oxygen), the release of combustible gas with a volume from 0.9 to 1.6 nm³ and calorific value from 7 to 11.5 MJ / nm³ is obtained.

In the experiments, the specific energy consumption for the gasification of waste exceeds the calculated ones by 15-20%. This is due to the errors in the plasmatron efficiency and installation as a whole.

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