Plasma processing of biomedical waste

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Abstract: This paper presents a thermodynamic analysis of the plasma processing of Biomedical Waste (BMW). It is shown that the final products do not contain toxic substances. From the organic mass of BMW synthesis gas was basically produced, and mineral part consists mainly of calcium oxide and contains no carbon. To realise plasma processing of BMW experimental installation with DC plasma torch of 30 kW power was developed. Thermodynamic analysis showed good agreement with the experiments.

Keywords: biomedical waste, plasma, plasma torch, box furnace, processing, synthesis gas

1. Introduction

One of the most serious environmental problems today is pollution by biomedical waste (BMW), which in most cases has undesirable properties such as toxicity, carcinogenicity, mutagenicity, fire. Currently stringent rules and conditions for the disposal of such wastes are introduced in industrialized countries. Sanitary and hygienic survey of typical solid biomedical waste, made in Belarus, Kazakhstan, Russia and other countries show that their risk to the environment is significantly higher than that of most chemical wastes. For example, in the case of medical waste, containing cytotoxic drugs, viruses, antibiotics, their danger is comparable with risk of contamination by radioactive waste of the highest and the average activity.

Processing of toxic BMW requires use of the most universal methods to ensure disinfection and disposal of any of their components. Such technology is a plasma technology of BMW neutralization and processing. To implement this technology plasma-chamber furnace was developed. It is intended for heating and thermal processing of lump or packaged into packages of organic and inorganic materials as well as for treatment and disposal of different types of waste, including the BMW [1].

To determine the optimum operating parameters its numerical and experimental studies have been conducted on the example of the processing of bone. The investigated bone tissue (bone of adult animal) has the following chemical composition (wt.%): $Ca_{10}(PO_4)_6(OH)_2$ – 70, C – 14, O – 9, N – 4, H – 2, S – 1.

2. Thermodynamic analysis

To perform thermodynamic calculations software package Terra was used [2]. Calculations were carried out in the temperature range 300 - 3000 K and a pressure of 0.1 MPa for the following original compositions of technological mixture: Variant 1: 10 kg of BMW + 1.5 kg of air; Variant 2: 10 kg of BMW + 3 kg of air; Variant 3: 10 kg of BMW + 5 kg of air; Variant 4: 10 kg of BMW + 1 kg of air + 0.5 kg of water steam. Variants 1-3 are models of dry bone tissue, and variant 4 is model of wet one.

Fig. 1 shows the variation of concentration of gaseous components depending on the BMW processing temperature (Variant 1). With increasing temperature, the concentration of synthesis gas ($CO + H_2$) increases to a maximum of 77.2% (CO - 35.2%, H_2 - 42.0%) at 1300 K, the concentration of methane (CH_4) is 0.2%, and concentration of oxidants ($CO_2 + H_2O$) does not exceed 0.35% (Fig. 1a). With further increase in temperature, the concentration of the synthesis gas decreases slightly, while the concentration of oxidants increases. Concentration of ballast nitrogen (N_2) remains constant over the entire temperature range, being 14.3%. At temperatures above 1600 K, a compound of calcium, phosphorus and sulfur appeared in the gas phase (Fig. 1b). Maximum concentration of molecular phosphorus (P_2) is 2.86% at 2000 K, phosphorus oxide (PO) - 11.1% at 3000 K, phosphoric anhydride (P_2O_3) - 0.18% at 2250 K, phosphorus sulphide (PS) - 0.6 % at 2150 K, atomic phosphorus (P) - 0.2% at 3000 K, calcium (Ca) - 1.2% at 3000 K, calcium hydroxide (CaOH and $CaOH_2$) - 0.8% at 3000 K.

Fig. 2 shows the variation of concentration of the condensed components depending on the process temperature. It can be seen that the carbon is fully transferred to the gas phase at temperature above 1300 K, and tricalcium phosphate ($Ca_3P_2O_8$) dissociates into calcium oxide (CaO) and phosphorus-containing compounds (P_2O_3, PO, PS, P_2 and P) at temperature above 2300 K. Calcium sulphide (CaS) remains in the condensed phase prior to 2100 K.

Threefold increase in the proportion of air in the system (Variant 3) causes reducing the concentration of synthesis gas to 53.4% due to increasing the concentration of ballasting nitrogen to 40.4% (1600 K).

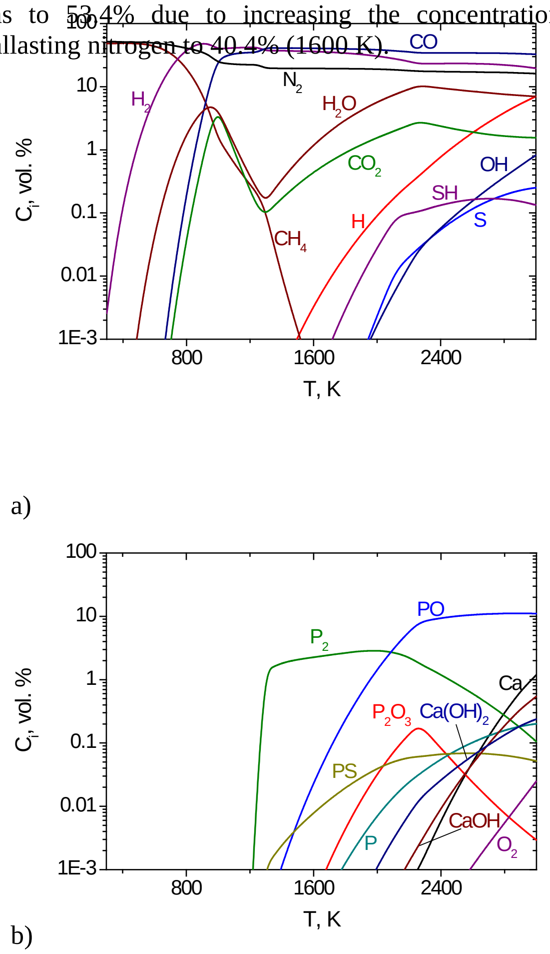

Fig. 1. Variation of the concentration of organic (a) and inorganic (b) components of the gas phase depending on the temperature of the BMW processing (Variant 1).

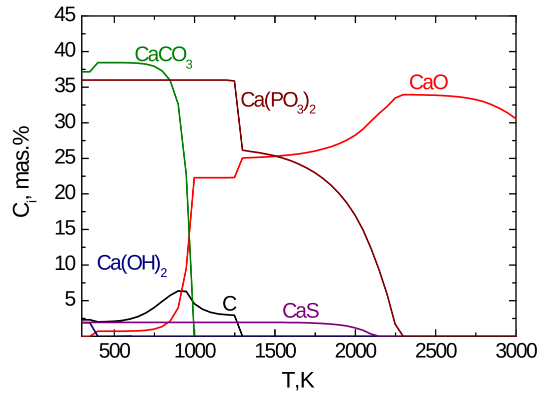

Fig. 2. Variation of the concentration of components of the condensed phase depending on the temperature of the BMW processing (Variant 1).

Carbon is gasified completely at 1000 K. In general, the behavior of components of both the gas and condensed phases qualitatively similar to those shown in Figs. 1 and 2. Moreover, the addition of steam to the system (Variant 4) does not change the qualitative behavior of the main components of the gas and condensed phase, and only affects the concentration of hydrogen in the synthesis gas either. In particular, the maximum hydrogen concentration reaches 55.4% at a temperature of 900 K versus 42% at 1250 K (Variant 1). Carbon is completely converted into the gaseous phase at a temperature of 1250 K.

Thus, when BMW processing from the organic mass is obtained mainly synthesis gas containing combustible components 77.4-84.6%, and the mineral part provided mainly calcium oxide and containing no carbon. Degree of gasification of carbon in all three variants reaches 100% in the temperature range of 1000-1250 K.

Specific power consumption for BMW processing (Fig. 3) increases with the temperature throughout its range for all three variants. Minimum power consumption corresponds to the Variant 3 with a maximum share of air in the system, due to the compensation of the endothermic effect of the processing by heat from the reaction of carbon oxidation.

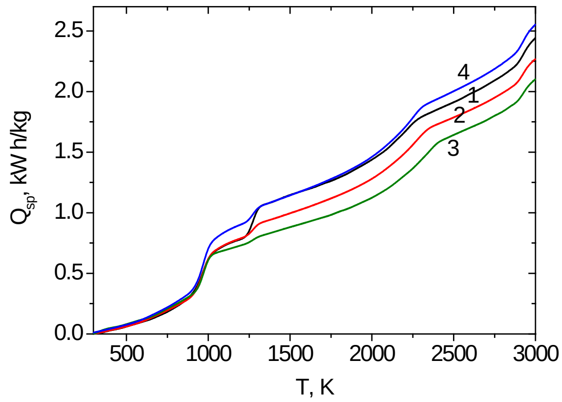

Fig. 3. Variation of specific power consumption for the BMW processing depending on the temperature: variants 1-4.

3. Experiment

Experimental studies were carried out in a plasma box furnace, which was a main element of the experimental installation (Fig. 4). This is device of periodic action. The arc plasma torch of 30 kW electric power is used for its heating [3].

The structure of the installation, except the plasma chamber furnace, includes systems of power supply and ignition of the plasma torch, as well as system of gas and water supply of the plasma torch with the combustion chamber of the furnace. Installation is supplied by system of sampling of the gaseous products for analysis.

Consumption of bone tissue G_m varied from 5.4 to 10.8 kg/h. Flow of plasma-forming air G_g was 3.6 kg/h. The ratio G_m/G_g varied from 1.8 to 3.0, which corresponds to the calculation under Variant 2.

Wastes are packed in boxes weighing 5-7 kg. They are placed in the furnace chamber, after which the loading door is closed. Under the influence of air plasma flame weight average temperature in the chamber reaches 1800 °C, the organic part of the waste is gasified and

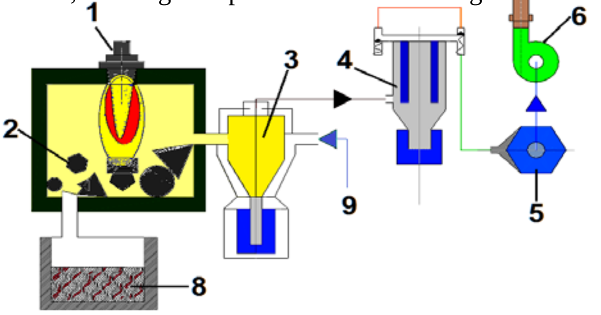

Fig. 4. Functional scheme of the experimental technological installation: 1- arc plasma torch; 2 - plasma box chamber; 3 - chamber for reburning; 4 - bag filter; 5 - ecological filter; 6 - exhaust fan; 7 - exhaust pipe; 8 - container for slag; 9 - air for reburning.

inorganic part of the waste is melted. The resulting synthesis gas is continuously withdrawn from the installation through the cooling and cleaning system. Molten mineral part of the waste is removed from the furnace after it has been stopped.

Experimental studies allowed determining operating modes of the plasma chamber furnace, the exhaust gases was analyzed, samples of condensed products in the combustion chamber were assembled and their chemical composition was determined. Gas at the outlet of the plasma furnace has the following composition (vol.%): CO - 63.4, H_2 - 6.2, N_2 - 29.6, S - 0.8. The total concentration of synthesis gas (CO + H_2) is 69.6%, which agrees well with the calculation. Yield of synthesis gas according to the calculation at 1800 K was 64.9%. The discrepancy between the experiment and calculation does not exceed 6.8%.

Loss on ignition (LOI) of the samples collected in the furnace combustion chamber and condensed material from the filter were determined. In accordance with standard procedure determining LOI, calcinations of the samples were carried out at a temperature 700 °C within 90 minutes. LOI of the samples taken in the chamber varied from 6.68 to 14.3% and LOI of the samples collected from the filter varied from 0.43 to 2.9%.

X-ray spectrum microanalysis of the products obtained in the experiments showed the following element composition in the samples collected in the chamber furnace, wt.%: Ca – 54.63, P – 12.91, O – 31.97. These elements were in the forms of oxides CaO (76.44 wt.%) and P_2O_3 (22.92 wt.%). Also traces of Al, Si and K were found. The carbon content in the sample was 2.9 wt. %.

Analysis of the condensed products collected in the filter on exit of the chamber furnace showed the following contents of elements, wt. %: Ca - 41.45, P - 14.09, O - 32.99, Si - 0.48, K - 1.48, S - 1.14, Fe - 1.73. All the elements present in the sample in the form of oxides, wt.%: CaO – 66.94, P_2O_3 – 25.0, SiO_2 – 1.02, K_2O – 1.61, SO_2 – 1.02, Fe_2O_3 – 2.48. These results for the most stable nonvolatile component in the condensed phase (CaO) correlate with calculated data: CaO – 71.61 wt.%. The discrepancy between experimental and calculated CaO concentrations does not exceed 7%.

Specific power consumption for processing of bone tissue in the plasma chamber furnace by results of experiments varies from 3.45 kWh/kg to 4.56 kWh/kg.

Developed as a result of the research installation for plasmochemical neutralization and processing of biomedical waste is planned to be used in medical institutions, research laboratories and biomedical industries. It is possible to implement a mobile version of the installation, which designed for serving small medical institutions. The developed installation can be used to study and implement other processes.

4. Acknowledgements

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5. References

[1] A.L. Mosse, A.V. Gorbunov and V.V. Sauchyn. “Plasma furnaces for toxic waste processing”. *J. High Temperature Mat. Process.*, **11**, 205-218 (2006)

[2] M. Gorokhovski, E.I. Karpenko, F.C. Lockwood, V.E. Messerle, B.G. Trusov and A.B. Ustimenko. “Plasma technologies for solid fuels: experiment and theory”. *J. Energy Inst.*, **78**(4), 157-171 (2005)

[3] S.A. Zhdanok and A.L. Mosse. “Plasma methods for Toxic Wastes Processing”. in: *Plasma Assisted Decontamination of Biological and Chemical Agents*. (Springer Science + Business Media BV) 143-149 (2008)