

PLASMACHEMICAL PROCESSING OF MEDICOBIOLOGICAL WASTES

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The process of processing medicinal wastes by plasma methods has been investigated. Thermodynamic calculations of the processing of wastes have been performed using bones of animal origin as an example. Experimental investigations were carried out in a plasma chamber furnace equipped with an electric arc plasmatron of power 30 kW.

Keywords: medicobiologic wastes, plasma methods, thermodynamic calculations, plasma chamber furnace.

A most important ecological problem facing many countries is the contamination of the surrounding medium by different kinds of dangerous wastes. The population explosion and scientific-technological progress have led to a situation such that in the surrounding medium enormous amounts of wastes are accumulated that surpass the possibilities of natural ecosystems. Utilization of wastes containing toxic substances and the absence of specially assigned places for destroying products with expired storage life remain an acute problem.

At the present time, solid domestic garbage and medicobiological wastes (MBW) are not being processed on the territory of the Republic of Kazakhstan. Every year in this country the amounts of dangerous wastes of medicinal origin requiring destruction come to about 35 tons. Up to the present time, the problem of utilization of MBW was considered not to be pressing in many countries of the world, which was also in accord with the world-wide assessment of its importance. However, the sanitary-and-hygienic investigations of typical medicinal wastes carried out as in Kazakhstan, Russia, Belarus, so abroad [1, 2] show that their hazard to the surrounding medium is much higher than of the majority of chemical wastes. For example, the danger in the case of solid wastes containing cytostatic preparations and antibiotics is comparable with that of contamination by radioactive wastes of high and middle levels of activity.

In this article we present the results of a thermodynamic analysis of the process of thermal processing of MBW and the description of the plasma installation that was used for their processing. The investigated MBW was a bony tissue (bones of animal origin) that had the following chemical composition (wt.%): 70 of $\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$, 14 of C, 9 of O, 4 of N, 2 of H, and 1 of S.

To carry out the thermodynamic calculations, we used the TERRA software suite [3]. The calculations were performed for temperatures of up to 3000 K and pressure of 0.1 MPa for the following compositions of the initial technological mixture:

- 1) 10 kg MBW + 1.5 kg air;
- 2) 10 kg MBW + 3 kg air;
- 3) 10 kg MBW + 5 kg air;
- 4) 10 kg MBW + 1 kg air + 0.5 kg steam.

Variants 1–3 model a dry bony tissue and variant 4, a moist one.

Figure 1 shows the change in the concentration of gaseous components depending on the temperature of the process of processing MBW (variant 1). The concentration of the synthesis gas ($\text{CO} + \text{H}_2$) increases with temperature to a maximum value of 77.2 vol.% (35.2 vol.% of CO, 42.0 vol.% of H_2) at $T = 1300$ K, with the concentration of methane (CH_4) coming to

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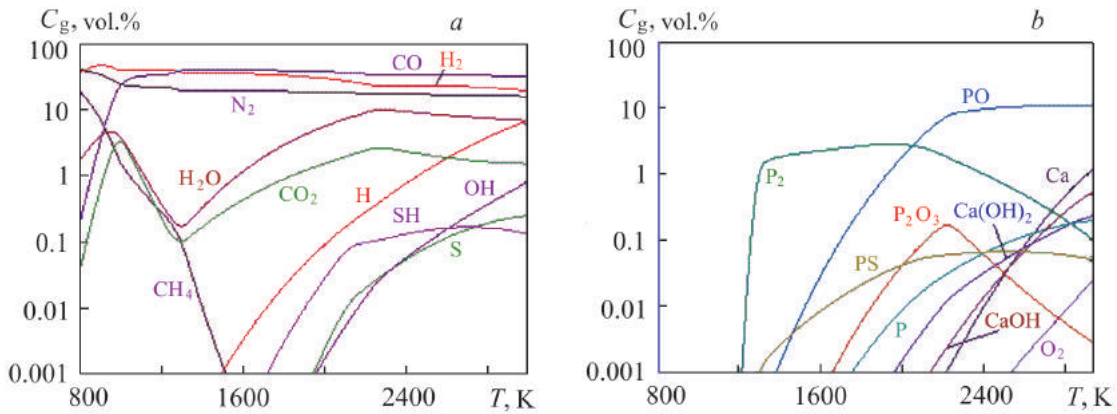


Fig. 1. Change in the concentrations of organic (a) and inorganic (b) components of the gaseous phase depending on the temperature of processing MBW (variant 1).

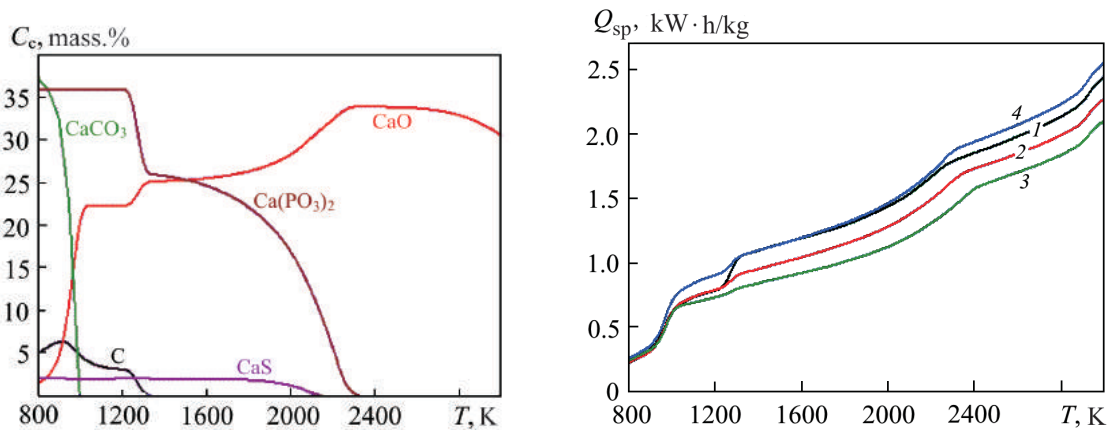
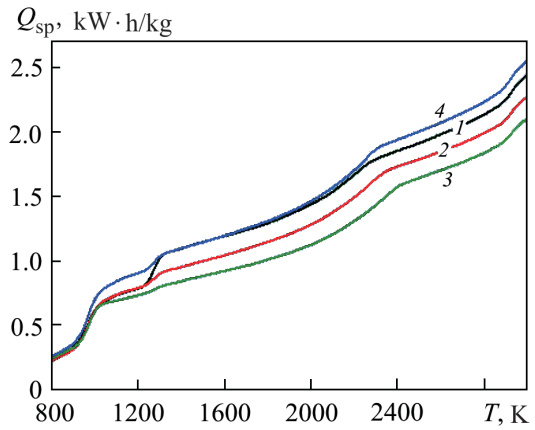


Fig. 2. Change in the concentrations of the condensed phase components depending on the temperature of processing MBW (variant 1).

Fig. 3. Change in the specific energy (Q_{sp}) spent on processing MBW depending on the temperature of the process for different compositions of the initial technological mixture: 1–4) variants 1–4, respectively.



0.2 vol.% and that of oxidizer ($CO_2 + H_2O$) not exceeding 0.35 vol.% (Fig. 1a). On further increase in the temperature, the concentration of the synthesis gas decreases insignificantly, whereas that of the oxidizer increases. The concentration of the ballasting nitrogen (N_2) remains constant in the entire temperature range and comes to 14.3 vol.%. At a temperature above 1600 K compounds of calcium, phosphorus, and sulfur appear in the gaseous phase (Fig. 1b). The maximum concentration of the molecular phosphorus (P_2) amounts to 2.86 vol.% at $T = 2000$ K, of phosphorus oxide (PO) to 11.1 vol.% at 3000 K, of phosphorus anhydride (P_2O_3) to 0.18 vol.% at 2250 K, of phosphorus sulfide (PS) to 0.6 vol.% at 2150 K, of atomic phosphorus (P) to 0.2 vol.% at 3000 K, of calcium (Ca) to 1.2 vol.% at 3000 K, and of calcium hydroxides ($CaOH_2$ and $CaOH$) to 0.8 vol.% at 3000 K.

Figure 2 shows the change in the concentration of condensed components depending on the temperature of the process. It is seen from the figure that carbon is converted entirely into a gaseous phase at a 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 a temperature above 2300 K. Calcium sulfide (CaS) is retained in the condensed state right to $T = 2100$ K.

On threefold increase in the fraction of air in the system (variant 3), the concentration of the synthesis gas decreases to 53.4 vol.% due to the increase in the concentration of the ballasting gas nitrogen up to 40.4 vol.% ($T = 1600$ K). Carbon is

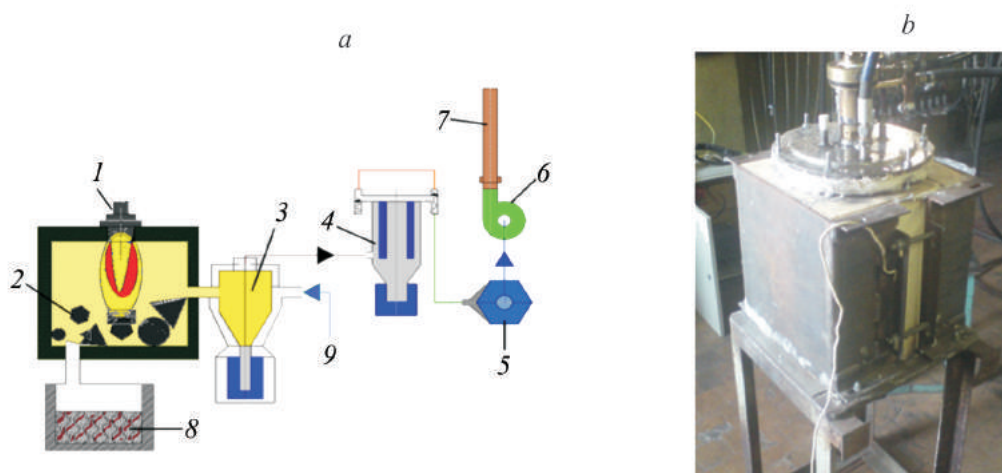


Fig. 4. Basic diagram (a) and photograph (b) of the experimental technological installation for processing MBW: 1) PL-03/30 electric arc plasmatron; 2) PCF-03 chamber furnace; 3) after-burner chamber; 4) bag filter; 5) ecological filter; 6) exhaust fan; 7) exhaust pipe; 8) contained for slag collection; 9) air for after-burning.

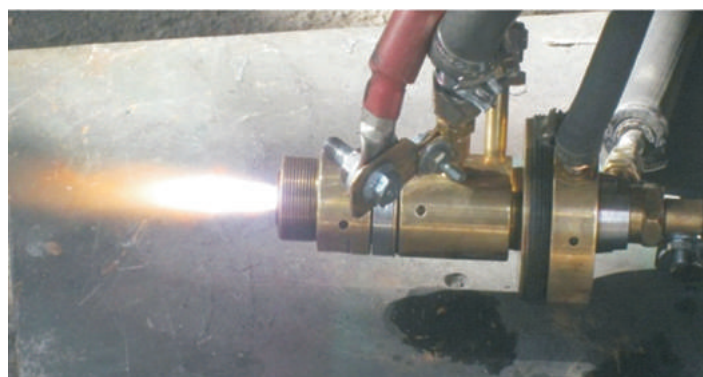


Fig. 5. PL-03/30 plasmatron.

converted entirely into a gaseous phase even at $T = 1000$ K. On the whole, the behavior of the components in both the gaseous and condensed phases is qualitatively similar to that presented in Figs. 1 and 2. Furthermore, addition of steam to the system (variant 4) also does not cause a qualitative change in the behavior of the main components of the gaseous and condensed phases and only exerts its influence on the concentration of hydrogen in the synthesis gas. In particular, the maximum concentration of hydrogen reaches 55.4 vol.% even at a temperature of 900 K as against 42 vol.% at $T = 1250$ K (variant 1). Carbon is entirely converted into a gaseous phase at 1250 K.

Thus, the processing of MBW composed of an organic mass mainly yields a synthesis gas with the content of combustible components 77.4–84.6 vol.%, with the mineral part not containing carbon and being represented mainly by calcium oxide. In all three variants, the degree of the gasification of carbon reaches 100% in the temperature range 1000–1250 K.

The specific expenditures of energy for processing MBW (Fig. 3) increase with the temperature in its entire range for all four variants of calculation. In the range of the optimal temperatures of MBW processing ($T = 1200$ – 1600 K), the specific energy expenditures vary within the range 0.7–1.2 kW·h/kg. The minimum energy expenditures correspond in this case to variant 3 with the maximum fraction of air in the system, which is connected with the compensation of the endothermal effect of processing by heat release at the expense of carbon oxidation reaction.

Experimental investigations were carried out in a plasma chamber furnace. This is a batch-operated facility for the heating of which a PL-03/30 electric arc plasmatron of electric power of up to 35 kW is used [4–6]. The plasma chamber furnace is intended for plasmachemical processing toxic MBW of different origin formed at medicinal institutions,

including those producing medicinal preparations. The height of the chamber furnace is 0.33 m, the length is 0.22 m, its width is 0.22 m, and the lining thickness is 0.04 m. The mass of charged wastes varies approximately from 5 to 7 kg depending on their composition. The time of the full cycle of processing wastes, with account for the furnace cooling-off, is about 30 min.

Apart from the plasma chamber furnace, the technological installation contains the system of electric power supply and that of starting the plasmatron, as well as the systems of gas and water supply for the plasmatron and the combustion chamber of the furnace. The installation is equipped with a system of sampling gaseous products of the process for their analysis.

For lack of oxygen in the plasma-forming gas (air), only gasification of wastes (their partial combustion) occurs in the combustion chamber of the furnace. According to the scheme of the experimental technological installation presented in Fig. 4, the formed gaseous mixture moves from the combustion chamber into an after-burner chamber into which air is supplied additionally for complete after-burning of fluent gases. To prolong the time during which the gas mixture is held at a high temperature, the after-burner chamber is made in the form of a cyclone furnace with account for the fact that complete decomposition of dioxins requires that the gas be held at a temperature of 1500 K for two seconds. On the inside the chamber is lined with a refractory material for maintaining a high temperature. The consumption of the air fed to the after-burner chamber is 0.2 kg/s. As shown in Fig. 4, on leaving the after-burner chamber the gaseous mixture enters a gas cleaning system.

It should be noted that for the final cleaning of the gases leaving the installation, we used an ion exchanger of type RIF-FKh-0.5 developed and manufactured by the "IMT-Filtr" Limited Corporation. Filters of this type with the ion-changing filtering material Fiban are intended for freeing gases from toxic compounds, acid aerosols, alkalis, and salts in the exhaust and recirculation systems of the installations in the chemical and other industries. The cleaning of gases in ion exchanger occurs as a result of chemical reactions between the gas molecules and the functional groups of the ion-exchanging fibrous materials Fiban forming the basis of filtering elements. Due to the chemical binding of a toxic admixture by ion-changing filtering materials, a high degree of cleaning is achieved. The ion exchanger operates in the automatic or manual regime of regeneration and is regenerated by water or by a solution of corresponding reagent. An RIF-FKh-0.5 ion exchanger in a single module has a cleaned air output of 500 m³/h.

The main element of the installation is a direct current PL-03/30 plasmatron of linear scheme presented in Fig. 5. The photograph is made during bench tests at a power of 20 kW at a flow rate of the plasma-forming air of $1.5 \cdot 10^{-3}$ kg/s. The luminescent part of the plasma flare is equal to more than 20 calibers. The volt-ampere characteristic (VAC) of the PL-03/30 plasmatron operating on air is given in Fig. 6.

The dependences of the power N supplied to the plasmatron on the current strength of the arc I are presented in Fig. 7. On change in the flow rate of the plasma-forming gas from 0.8 to 3.8 g/s and of the current strength from 170 to 260 A in the case of using an anode with the nozzle diameter $d_a = 10$ mm, the plasmatron power increases from 11 to 22.5 kW.

In the experiments, the bone tissue consumption G_m changed within $(1.5-3) \cdot 10^{-3}$ kg/s. The amount of the plasma-forming air G_g reached 3.6 kg/h. The ratio G_m/G_g is equal to 1.8-3, which corresponds to the calculation of variant 2.

Wastes of mass 5-7 kg packed up into bags or boxes are placed in the chamber of the furnace, after which the loading hatch is closed. Under the action of the air plasma flare the mean-mass temperature in the chamber attains 1800 K, the organic part of the wastes is gasified, whereas the inorganic part is melted. The synthesis gas obtained is extracted through the system of cleaning and cooling and is continuously removed from the installation. The melted mineral part of the wastes is taken out of the furnace when the latter is brought to a stop.

As a result of the experimental investigations, we determined the regimes of operation of the plasma chamber furnace, analyzed the effluent gases, obtained samples of the condensed products extracted from the combustion chamber, and determined their chemical composition. At the outlet from the plasma furnace the effluent gas had the following composition (vol.%): 63.4 of CO; 6.2 of H₂; 29.6 of N₂, and 0.8 of S. The total concentration of the synthesis gas (CO + H₂) was 69.6 vol.%, which agrees well with the results of calculation. According to the calculation, the gas output at 1800 K was 64.9 vol.%. The difference between the experiment and calculation does not exceed 6.8%.

We carried out an X-ray microspectrum analysis of the products obtained in the experiments. We established that the sample of the products collected in the combustion chamber of the furnace after carrying out an experiment was composed of (wt.%): Ca 54.6; P 12.9; O 32 that are present in the form of oxides, CaO 76.4 and P₂O₃ 22.9. There are also traces of Al, Si, and K. The content of carbon in the sample was equal to 2.9 wt.%.

Analysis of the condensed products collected on the filter downstream of the combustion chamber of the furnace showed the following content of elements (wt.%): Ca 41.5; P 14.1; O 33; Si 0.5; K 1.5; S 1.1, and Fe 1.7. All the elements are present in the sample in the form of oxides (wt.%): CaO 67; P₂O₃ 25; SiO₂ 1; K₂O 1.6; SO₂ 1, and F₂O₃ 2.5. These results for

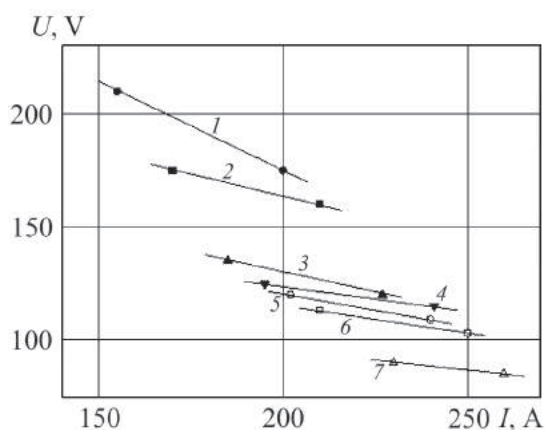


Fig. 6. VAC of the PL-03/30 plasmatron with anode of inner diameter $d_a = 10$ mm at different air flow rates: 1) $3.82 \cdot 10^{-3}$ kg/s; 2) $2.97 \cdot 10^{-3}$; 3) $2.54 \cdot 10^{-3}$; 4) $2.12 \cdot 10^{-3}$; 5) $1.7 \cdot 10^{-3}$; 6) $1.27 \cdot 10^{-3}$; 7) $0.85 \cdot 10^{-3}$.

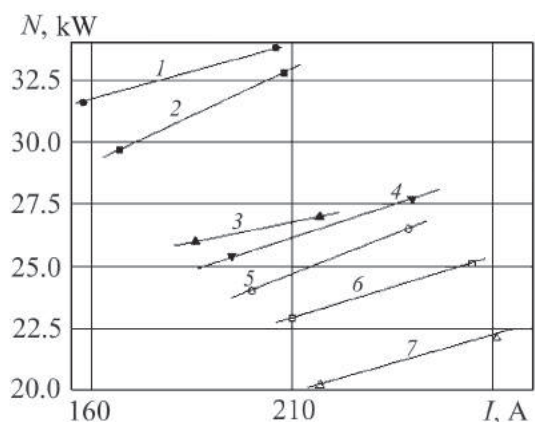


Fig. 7. VAC of the PL-03/30 plasmatron with anode of inner diameter $d_a = 10$ mm in the form of the dependence of electric power on the current strength in the arc at air flow rates: 1) $3.82 \cdot 10^{-3}$ kg/s; 2) $2.97 \cdot 10^{-3}$; 3) $2.54 \cdot 10^{-3}$; 4) $2.12 \cdot 10^{-3}$; 5) $1.7 \cdot 10^{-3}$; 6) $1.27 \cdot 10^{-3}$; 7) $0.85 \cdot 10^{-3}$.

the most stable nonvolatile component in the condensed phase (CaO) correlate with the results of calculations: CaO 71.61 wt.%. The difference between the experimentally obtained and calculated concentrations of CaO does not exceed 7%.

The experimental data on the specific energy expended on the technological process of processing a bony tissue in a plasma furnace vary from 3.5 to 4.6 kW·h/kg. Such a significant discrepancy between the calculated (Fig. 3) and experimental values of specific energy expenditures on the process is attributed to the fact that in the thermodynamic calculations we determine the maximum possible energy expenditures in an isolated thermodynamic system without accounting for the heat exchange with the environment. In practice, both the plasma chamber furnace itself and plasmatron are characterized by considerable thermal losses into the surrounding medium with a cooling water.

It is planned to use the installation, developed as a result of the carried out investigations, for plasmachemical detoxication and processing of MBW in medicinal institutions, scientific-research laboratories, and medicobiologic enterprises. The practical realization of a mobile variant of this installation is possible. It is intended for small-scale enterprises. The developed and tested variants of the facility can be used for studying other technological processes and their realization.

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