Plasma processing of waste from the woodworking industry: numerical analysis and experiment

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The most common method of utilization of waste from the woodworking industry is its incineration to generate thermal energy and followed by disposal of the resulting ash at a special landfill. The method has serious disadvantages, such as the formation of highly toxic chemical compounds, such as dioxins, furan and benzo(a)pyrene. An alternative method is the plasma gasification of this waste with the production of a combustible gas (Brattsev et al., 2011). Plasma gasification of waste allows to intensify the process of obtaining combuctible gas, consisting mainly of synthesis gas (CO + H_2). Synthesis gas can be used as the working fluid of a new generation of highly efficient electric generators, including solid oxide fuel cells.

Waste from the woodworking industry consists of a mixture of sawdust and wood chips. Their characteristic chemical composition is represented by the following components (Graedel and Allenby, 2003), wt.%: C – 49.88, O – 43.81, H – 5.98, N – 0.1, SO_3 – 0.01, P_2O_5 – 0.02, Na_2O – 0.01, K_2O – 0.01, CaO – 0.12, MgO – 0.02, MnO – 0.01, Fe_2O_3 – 0.01, Al_2O_3 – 0.01, SiO_2 – 0.01. The organic part of wood waste is represented by carbon, oxygen and hydrogen with a total concentration of 99.67%, while the mineral part is only 0.33%. Their higher calorific value is 18450 kJ/kg (Demirbaş and Demirbaş, 2004).

To carry out the thermodynamic analysis of plasma gasification of waste, the universal program for calculating multicomponent heterogeneous systems TERRA, developed for high-temperature processes, was used (Messerle et al., 2018). The TERRA program has its own database of thermodynamic properties of about 3000 individual substances in the temperature range of 300–6000 K. Calculations of plasma gasification of waste from the woodworking industry were carried out in the temperature range of 300–3000 K at a pressure of 0.1 MPa for the following thermodynamic system, mass fractions: 1 Waste + 1 air. The purpose of the calculations was to determine the integral indicators of the process: the equilibrium composition of the gas phase of the gasification products, the degree of carbon gasification, and the specific energy consumption for the process.

Figure 1 shows the change in the concentration of gaseous components depending on the temperature of the plasma-air gasification of waste. As the temperature rises, the synthesis gas yield increases to a maximum at T = 1600 K. The maximum concentration of combustible synthesis gas components reaches 71.6 vol.% (41.9% CO, 29.7% H_2). The degree of carbon gasification reaches 100% at a temperature of 1200 K. Carbon completely passes into the gas phase, forming CO at temperatures above 1200 K. The specific energy consumption for the waste gasification increases with temperature and by a temperature T = 1600 K, at which the synthesis gas yield reaches its maximum, it is 1.25 kW·h/kg. Such moderate energy consumption for the plasma-air gasification of waste is associated with the compensation of the endothermic effect due to the heat of the reactions of carbon oxidation with atmospheric oxygen.

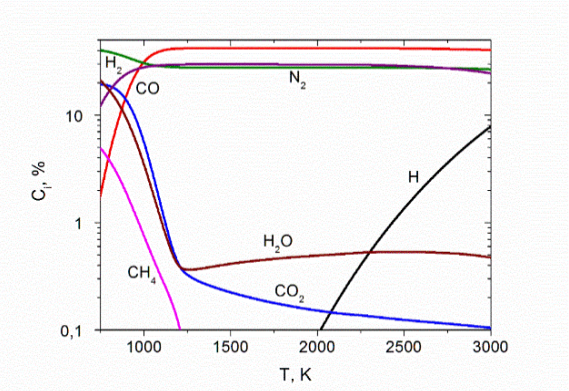

Figure 1. Concentration of gaseous components depending on the temperature of waste air gasification.

Experiments on waste gasification were carried out at the installation, the main elements of which are a DC plasma torch with a nominal power of 70 kW (Messerle et al., 2018). In addition to reactor 2 with plasma torch 3 (Fig. 2), the experimental setup includes systems for supplying plasma gas and cooling water to the

plasma torch and reactor, system of power supply, plasma torch control, and exhaust gas purification. The experimental setup is equipped with a system for sampling gaseous waste gasification products for their subsequent analysis. The condensed products of the gasification process accumulated at the bottom of the reactor and were taken for analysis after it was turned off.

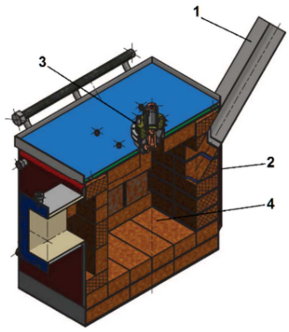

Figure 1. Scheme of a plasma reactor for waste gasification (cross section): 1 – pipe for loading briquetted waste into the reactor, 2 – plasma reactor, 3 – DC electric arc plasma torch, 4 – waste gasification zone.

At a plasma torch power of 72.6 kW (I = 220 A, U = 330 V), the flow rate of plasma-forming air was 250 l/min. After starting the plasma torch and heating the inner surface of the lining of the bottom part of the reactor to a temperature of 1215 K (about 15 minutes), briquettes with sawdust and wood chips were fed into the gasification zone through the pipe for loading briquetted waste into the reactor. The mass of each briquette was 0.33 kg. The measured temperature in the bottom part of the reactor was 1560 K. Under the influence of the plasma-air torch, the average-mass temperature in the reactor reached 1600 K. At this temperature, the organic part of the waste was gasified, and the inorganic part (slag and ash) accumulated at the bottom of the reactor and in the bag filter. The ash was removed from the reactor after the plasma torch was turned off and the reactor cooled down. The plasma torch was turned off 25 minutes after loading the first briquette with waste. During this time, 30 briquettes with a total weight of 9.9 kg were gasified, which corresponded to a reactor productivity of 23.8 kg/h at a plasma air flow rate of 23.6 kg/h. At the output of the plasma reactor, the following gas composition was obtained, vol.%: CO – 42.0, H_2 – 25.1, N_2 – 32.9. The specific heat of combustion of the gas formed during the plasma-air gasification of the waste was 9450 kJ/kg. After gasification of 9.9 kg of sawdust and wood chips, 0.013 kg of slag was collected from the bottom of the reactor. This amount of slag is about 0.2% of the initial waste mass. The residual fly ash (0.1%) was carried away by the flue gases. The flue gas flow measured with a volume flow meter was 48.3 kg/h. The content of residual carbon in the slag sample was 1.13 wt.%, which corresponded to the degree of biomass carbon gasification 96.6%. Residual carbon analysis was performed using an absorption gravimetric method. The specific energy consumption for the process was 1.53 kWh/kg.

Comparison of the main integral indicators of the biomass plasma processing process showed satisfactory agreement between the calculated and experimental data with their discrepancy not exceeding 18%. Both in calculations and in experiments, no harmful impurities were found in the products of plasma-air gasification of the studied wastes, which confirms the environmental efficiency of the plasma waste processing technology.

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