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Thermodynamic Analysis and Experimental Study of Agricultural Waste Plasma Processing

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Abstract : A large amount of manure and its irrational use negatively affect the environment. As compared with biomass fermentation, plasma processing of manure enhances makes it possible to intensify the process of obtaining fuel gas, which consists mainly of synthesis gas ($CO + H_2$), and increase plant productivity by 150–200 times. This is achieved due to the high temperature in the plasma reactor and a multiple reduction in waste processing time. This paper examines the plasma processing of biomass using the example of dried mixed animal manure (dung with a moisture content of 30%). Characteristic composition of dung, wt.%: H_2O – 30, C – 29.07, H – 4.06, O – 32.08, S – 0.26, N – 1.22, P_2O_5 – 0.61, K_2O – 1.47, CaO – 0.86, MgO – 0.37. The thermodynamic code TERRA was used to numerically analyze dung plasma gasification and pyrolysis. Plasma gasification and pyrolysis of dung were analyzed in the temperature range 300–3,000 K and pressure 0.1 MPa for the following thermodynamic systems: 100% dung + 25% air (plasma gasification) and 100% dung + 25% nitrogen (plasma pyrolysis). Calculations were conducted to determine the composition of the gas phase, the degree of carbon gasification, and the specific energy consumption of the processes. At an optimum temperature of 1,500 K, which provides both complete gasification of dung carbon and the maximum yield of combustible components (99.4 vol.% during dung gasification and 99.5 vol.% during pyrolysis), and decomposition of toxic compounds of furan, dioxin, and benz(a)pyrene, the following composition of combustible gas was obtained, vol.%: CO – 29.6, H_2 – 35.6, CO_2 – 5.7, N_2 – 10.6, H_2O – 17.9 (gasification) and CO – 30.2, H_2 – 38.3, CO_2 – 4.1, N_2 – 13.3, H_2O – 13.6 (pyrolysis). The specific energy consumption of gasification and pyrolysis of dung at 1,500 K is 1.28 and 1.33 kWh/kg, respectively. An installation with a DC plasma torch with a rated power of 100 kW and a plasma reactor with a dung capacity of 50 kg/h was used for dung processing experiments. The dung was gasified in an air (or nitrogen during pyrolysis) plasma jet, which provided a mass-average temperature in the reactor volume of at least 1,600 K. The organic part of the dung was gasified, and the inorganic part of the waste was melted. For pyrolysis and gasification of dung, the specific energy consumption was 1.5 kWh/kg and 1.4 kWh/kg, respectively. The maximum temperature in the reactor reached 1,887 K. At the outlet of the reactor, a gas of the following composition was obtained, vol.%: CO – 25.9, H_2 – 32.9, CO_2 – 3.5, N_2 – 37.3 (pyrolysis in nitrogen plasma); CO – 32.6, H_2 – 24.1, CO_2 – 5.7, N_2 – 35.8 (air plasma gasification). The specific heat of combustion of the combustible gas formed during pyrolysis and plasma-air gasification of agricultural waste is 10,500 and 10,340 kJ/kg, respectively. Comparison of the integral indicators of dung plasma processing showed satisfactory agreement between the calculation and experiment.

Keywords : agricultural waste, experiment, plasma gasification, thermodynamic calculation
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