STEAM AND CARBON DIOXIDE GASIFICATION OF SUNFLOWER SEED HUSKS BY GASEOUS DETONATION PRODUCTS

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Abstract: Sunflower seed husks (SSH) are a waste product of the oil and fat industry with a daily accumulation volume of up to one thousand tons in the Russian Federation. The contents of C, O, H, and N in dry SSH are 50.28, 40.5, 6.31, and 0.74 %(wt.), respectively; the mineral components in SSH (ash content 2.17 %(wt.)) are represented, mainly, by compounds of S, K, Ca, Mg, P, Cl, and Si; and the higher calorific value of SSH is 19.2 MJ/kg. The objective of this study is to determine the optimal conditions for the allothermic gasification of SSH using gaseous detonation products as a high-temperature steam/carbon dioxide gasifying agent (GA) and to demonstrate the feasibility of "self-feeding" the gasification process, i. e., utilizing the obtained syngas to generate the GA, through thermodynamic calculations and a laboratory experiment. The best conditions for SSH gasification are understood to be the ratio of SSH/GA mass flow rates that achieves the highest gas yield with the lowest CO_2 content. Thermodynamic calculations have shown that the SSH gasification process with the detonation products of the stoichiometric oxygen mixture of the starting fuel (natural gas) and the stoichiometric oxygen mixture of the syngas should be carried out at a pressure of 0.1 MPa, a GA temperature of at least 1500 K, and an SSH/GA mass ratio of 2.2–1.8 with the resulting dry gas containing up to 53 %(vol.) CO and 47 %(vol.) H_2, having the higher calorific value of at least 15.5 MJ/kg and allowing self-feeding of the gasification process with a self-feeding coefficient (the ratio of gas consumption for self-feeding to the total gas yield) of less than 19%. Two series of experiments on the gasification of SSH with an average SSH/GA mass ratio of ≈ 2 were conducted on a laboratory flow-through setup. A pulse-detonation gun (PDG) operating at 1 Hz was used to generate GA, primarily consisting of H_2O and CO_2. In the first series, the GA was generated from the products of gas detonation of a stoichiometric oxygen mixture of natural gas, expanded to atmospheric pressure. The objectives of this series were to obtain and accumulate a sufficient quantity of dry primary syngas with the lowest possible CO_2 content. The primary dry gas obtained in this series of experiments contained, on average, 37.7 %(vol.) CO, 25.3 %(vol.) H_2, 7.4 %(vol.) CH_4, 8.6 %(vol.) C_xH_y, and 21 %(vol.) CO_2, with the heaviest C_xH_y hydrocarbon recorded being propane (less than 0.1 %(vol.)); i. e., condensable hydrocarbons (tar) were absent from the resulting gas. In the second series, the detonation products of a stoichiometric oxygen mixture of the primary syngas, expanded to atmospheric pressure, were used as the GA. The objectives of this series were to obtain and accumulate a sufficient quantity of dry secondary gas with the lowest CO_2 content and to test its detonability in a mixture with oxygen. It turned out that the secondary dry gas obtained in this series of experiments contained, on average, 44.4 %(vol.) CO, 18.5 %(vol.) H_2, 5.0 %(vol.) CH_4, 2.1 %(vol.) C_xH_y, and 30 %(vol.) CO_2. The average detonation velocity of this gas in a stoichiometric oxygen mixture measured in the PDG was 1730 ± 50 m/s, i. e., the possibility of self-feeding the PDG with the produced syngas was proven experimentally. The experimental value of the self-feeding coefficient was approximately equal to 60%. The difference in the calculated and measured compositions of the produced gas and in the self-feeding coefficient values is apparently due to heat losses and off-design conditions of reagent mixing in the experiment.

Keywords: sunflower seed husks; allothermal gasification; steam; carbon dioxide; syngas; pulse-detonation gun; self-feeding

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Figure Captions

Figure 1 Schematic of the experimental setup

Figure 2 Equilibrium compositions of the SSH gasification products in the starting GA environment (left column) and the corresponding equilibrium compositions of dry syngas (right column) depending on the mass ratio $m = \mathrm{SSH/GA}$ at different values of temperature ((*a*) $T_g = 1200$ K; (*b*) 1500; and (*c*) $T_g = 2000$ K) and pressure (solid curves — 0.1 MPa and dashed curves — 0.4 MPa); starting GA is represented by detonation products of the stoichiometric methane–oxygen mixture

Figure 3 Recordings of gas temperature (T_g) and the reactor wall temperature (T_w) as well as overpressures in the syngas storage tank (P_{sg}) and in the reactor (P_r) in one of the experiments on obtaining and accumulating dry primary syngas

Figure 4 Recordings of gas temperature (T_g) and the reactor wall temperature (T_w) as well as overpressures in the syngas storage tank (P_{sg}) and in the reactor (P_r) in one of the experiments on obtaining dry secondary syngas; the enlarged inset shows the record of syngas overpressure in the syngas storage tank

Table Captions

Table 1 Elemental composition of SSH (%(wt.)) obtained by elemental CHNS analysis

Table 2 Elemental composition of SSH (%(wt.)) obtained using scanning probe microscopy combined with energy-dispersive analysis

Table 3 Characteristics of GA and dry syngas during gasification of an SSH–GA mixture of stoichiometric composition with self-feeding of the process by the syngas at $T_g = 2000$ K and $p_g = 0.1$ MPa in six consecutive cycles

Table 4 Characteristics of GA and dry syngas during gasification of an SSH–GA mixture of stoichiometric composition with self-feeding of the process by the syngas at $T_g = 800$–2000 K and $p_g = 0.1$ MPa

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