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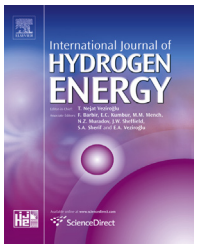

Co-gasification of coal/sewage sludge blends to hydrogen-rich gas with the application of simulated high temperature reactor excess heat

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ABSTRACT

The experimental study on oxygen and steam gasification and co-gasification of hard coal and sewage sludge to hydrogen-rich gas was performed in the laboratory scale fixed bed gasifier equipped with an auxiliary gasification agents pre-heating system, simulating the utilization of an excess High Temperature Reactor (HTR) heat. The allothermal gasification and co-gasification tests were performed on fuel blends of coal and sewage sludge of the total mass of 10 g and biowaste content of 20% and 40%w/w in three system configurations. In the first one the reactor was heated up with a resistance furnace to the temperature of 700 °C in the inert gas (nitrogen) atmosphere. When the temperature inside the reactor was stable, oxygen and steam of the temperature of approximately 100 °C were introduced into the reactor. In the second system, after the reactor was heated up to 700 °C, the heating of the reactor was switched off and oxygen and steam were pre-heated to the temperature of 700 °C and fed into the reactor. In the third system a fuel sample in the reactor was heated to the temperature 700 °C and the set temperature was maintained with the resistance furnace. The results showed that sufficient thermal energy required for an effective oxygen/steam gasification process was generated in systems with the external heating of the reactor. The highest hydrogen contents in gas were reported in coal gasification, irrespective of the system configuration. The total hydrogen volume decreased with increasing biomass content in a fuel blend in all studied system configurations.

Introduction

Meeting the increasing energy demand and securing the energy supplies based on the local energy resources is the serious challenge of the today world economies. Nuclear energy systems are often claimed to be effective and clean when compared to the fossil fuel based, carbon-intensive energy installation [1,2]. The wide implementation of such systems, however, also faces some severe difficulties, especially in economies traditionally based on fossil fuels. A promising concept of mitigation of carbon dioxide emission from coal-based energy systems consists in combination of coal gasification technologies, of higher efficiency and lower contamination emission levels than combustion systems [3], with utilization of the nuclear plant excess heat for endothermic reactions of the gasification process [4]. Further environmental advantages may be achieved when hydrogen, as clean

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energy carrier, is considered as the main product of the gasification process and when the partial replacement of the fossil fuel with renewable, and/or waste material is implemented [5–7]. Although the idea of the application of the nuclear excess heat in chemical processes is not new [8,9], the coal-nuclear synergy is still at the stage of demonstration [10,11]. In the latter case the High Temperature Reactors (HTRs) applying graphite balls containing uranium dioxide and thorium dioxide or uranium carbide and thorium carbide with helium as the cooling medium of the temperature of 700–950 °C, are of particular interest [12–14]. The process products include ammonia, liquid fuels [15,16] and hydrogen [13,17]. The HTRs based system performance has been extensively tested in Germany in 1970s and 1980s, to mention the Component Experimental Loop (KVK), Nuclear Long-Distance Energy (NFE), EVA and EVAII installations [10,11,18,19]. Considering the utilization of biowaste, a sewage sludge represent a significant problem to municipal and industrial waste water treatment plants. The expected production of the municipal sewage sludge in 2018 in Poland is over 0.7 million dry ton per year [20]. In Poland this kind of waste is primarily disposed to landfills. Gasification is the process which offers the high added value utilization of sewage sludge and requires the simplest pre-treatment of the raw material; the moisture content may be as high as 75%w/w [21]. In the paper the results of the experimental study on the effects of simulated HTR excess heat application in coal and sewage sludge co-gasification to hydrogen-rich with various gasification agent pre-heating system configurations are presented. The study contributes to and complement the research field concerned by implementing the waste carbonaceous material and co-gasification process as the thermochemical stage of the fossil fuel-nuclear system. The added economic and environmental value of the system proposed consists in utilization of a burdensome municipal waste in production of environment friendly energy carrier.

Methodology

Materials

Hard coal was sampled from a coal seam planned to be exploited by a coal mine in 5–10 years perspective, and the sewage sludge was provided by a municipal waste water treatment plant, both located in the Silesian region, Poland. The proximate and ultimate analyses of the tested fuels were performed in the accredited laboratories of the Department of Solid Fuels Quality Assessment (coal) and the Department of Environmental Monitoring (sewage sludge) of the Central Mining Institute, with the application of relevant standards, testing procedures and analyzers. These included:

- for coal analysis: automatic thermogravimetric analyzers LECO: TGA 701 or MAC 500 (contents of moisture, ash, volatiles acc. to PN-G-04560:1998 and PN-G-04516:1998), calorimeters LECO: AC-600 and AC-350 (heat of combustion acc. to PN-G-04513:1981), TruSpecCHN analyzer (contents of carbon, hydrogen, nitrogen acc. to PN-G-04571:1998) and TruSpecS analyzer (sulfur acc. to PN-G-04584:2001). Oxygen content was calculated as: 100% − W^a − A^a − C^a_t − H^a_t − S^a_c (PN-G-04510:1991), and fixed carbon as: 100% − W^a − A^a − V^a (PN-G-04516:1998)
- for sewage sludge analysis: moisture content acc. to the procedure SC-1.PB.02 ed. 5, ash content acc. to the procedure SC-1.PB.03 ed. 4; volatiles acc. to PN-G-04516:1998, carbon and sulfur content acc. to SC-1.PB.04 ed. 7; heat of combustion and calorific value acc. to the procedure SC-1.PB.22 d. 2; silica, aluminum, iron, calcium, magnesium, sodium, potassium, sulfur, titanium, phosphorus, barium, manganese and zinc oxides as well as trace elements with the application of wavelength dispersive X-ray fluorescence spectrometry.

The results are presented in Tables 1 and 2.

Experimental procedure

Fuel samples of a grain size below 0.2 mm, in analytical state, were placed at the bottom of the reactor between two layers of a quartz wool for better temperature distribution and avoidance of the entrainment of fuel particles by the gasification agents. The studied experiments were performed in the system presented in Fig. 1. The main element of the installation is the fixed bed reactor coupled with an auxiliary gasification agents pre-heating system, simulating the utilization of a HTR excess heat. Hydrogen-rich gas generation with pre-heated oxygen and steam as a gasification agent, was tested in three systems configurations. The reactor containing the studied fuel sample was first heated up with a resistance furnace with a heating rate of 1.33 °C/s to the set temperature in a nitrogen atmosphere in each of the system configurations tested. Next, in the system I, oxygen and steam as a gasification agent of the temperature of approximately 100 °C was introduced into the reactor, and the reactor was heated up with the external heat from the resistance furnace. In the system II the external heating of the reactor was switched off and the gasification agent was pre-heated to the temperature of 700 °C. In the system III the reactor was heated up with the external heat during the gasification step and additionally the

Table 1 – Basic physical and chemical parameters of hard coal (HC) and sewage sludge (SS) tested in analytical state.

No	Parameter	Unit	Fuel sample	
			HC	SS
1	Moisture, W	%w/w	7.44	1.81
2	Ash, A	%w/w	7.20	41.77
3	Volatiles, V	%w/w	32.37	41.52
4	Heat of combustion, Q_s	kJ/kg	27,815	11,090
5	Calorific value, Q_i,	kJ/kg	26,626	10,070
6	Ash sintering point, t_s	°C	940	–
7	Ash softening point, t_A	°C	1280	–
8	Ash melting point, t_B	°C	1360	–
9	Ash flow temperature, t_C	°C	1430	–
10	Total sulfur, S	%w/w	1.92	1.01
11	Carbon, C	%w/w	67.36	25.48
12	Hydrogen, H	%w/w	4.14	–
13	Nitrogen, N	%w/w	0.92	–