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Research article

Characteristics of novel synthetic fuels using coal and sewage sludge impregnated bioliquid applying for a coal combustion system

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ABSTRACT

The application of biomass resources and sewage sludge is currently the most important issue in the field of coal combustion systems. The main drawback for operating a boiler system is its varied firing characteristics and low heating value. In this study, we have developed new synthetic fuels, namely hybrid sludge fuel (HSF), using coal and sewage sludge impregnated bioliquid (molasses) and evaluated their properties by comparison with conventional fuels. To prepare the HSF, it was treated in a carbonization system at 250 °C. Depending on the van Krevelen diagram, the fuel quality of HSF was superior to that of raw bioliquid and sewage sludge. In addition, its fuel characteristic was similar to sub-bituminous and bituminous coal. Thermogravimetric analysis (TGA) indicated only a single-stage combustion pattern for HSF during non-isothermal heating. To clarify the unburned carbon (UBC) content, an ultimate analysis was conducted. The amount of UBC of the HSF was much more than that of sewage sludge, but less than that of coal. To investigate the surface hydrophobicity of HSF, Fourier transform infrared spectroscopy (FT-IR) analysis and a moisture re-adsorption test were carried out. The HSF possessed high hydrophobicity and presented a low moisture re-adsorption rate compared to conventional fuels.

1. Introduction

Biomass fuels may play a key role in the renewable energy sector due to concern about climate change. In Korea, the government plans to reduce greenhouse gas emissions by 37% from the business-as-usual (BAU) level by 2030 across all economic sectors [1]. In particular, coal as a primary energy source is responsible for approximately 40% of power generation in Korea. In spite of the necessity of using biomass resources to substitute for coal, there are difficulties involved in using them in pulverized coal (PC) power plants: 1) high moisture content, 2) low caloric value, 3) hydrophilic nature and 4) high bulk volume, which make transportation, handling and storage uneconomical [2]. In addition, the fibrous and unpulverized nature of biomass presents difficulties for existing milling and firing systems. Another challenge is the slagging and fouling phenomenon, caused by low melting ash containing a high proportion of alkali metals. Nonetheless, there has been much research into co-firing using both coal and biomass [3–8].

Sewage sludge has been considered as a renewable resource fuel for PC boiler systems, because ocean dumping of sewage sludge was prohibited by the London Convention [9]. Currently, coal-fired plants use sewage sludge along with coal in order to cope with the Renewable energy Portfolio Standard (RPS) in Korea. However, some limitations still remain regarding the direct substitution of sewage sludge as fuel in a coal power plant. Sewage sludge has high moisture and ash contents, resulting in a low heating value. Several studies [10–14] have evaluated the synergetic effect of sewage sludge and biomass mixture in the thermo-chemical conversion process to investigate fuel reactivity, pollutant emissions, gas composition and ash deposition. The studies suggest that biomass addition to sewage sludge can be one option for utilizing renewable energy resources in combustion systems.

Unfortunately, the aforementioned technical and economic challenges regarding biomass utilization have made biomass pre-treatment necessary. Another drawback of biomass and sewage sludge co-firing still remains, because it results in different combustion characteristics within a single boiler. In order to solve different fuel characteristics of fuel mixture, our research group has attempted to develop a two-in-one synthetic fuel using coal and biomass [15–18]. The synthetic fuel shows good combustion reactivity, single-stage burning characteristics,

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hydrophobicity and increased heating value. Recently, a new type of synthetic fuel using sewage sludge and biomass has been introduced based on this concept [19]. It shows better performance as a fuel than conventional sewage sludge. These kinds of synthetic fuels are prepared by impregnation of bioliquid into respective coal and sewage sludge. On the basis of our previous research results, we are convinced that such synthetic fuels can be one of the options for reducing the use of coal in coal-firing plants, because the characteristics of the synthetic fuel are similar to those of sub-bituminous and bituminous coal; and its use can also reduce CO_2 emissions.

This study concerns an advanced synthetic fuel combining three different resources. The new synthetic fuel, called hybrid sludge fuel (HSF), uses coal and sewage sludge impregnated bioliquid. A certain ratio of coal, sewage sludge and bioliquid was prepared and then moisture was removed using a fixed-bed carbonization system. In this study, HSF was prepared and assessed as an alternative fuel. The fuel characteristics of HSF were evaluated on the basis of H/C and O/C molar ratios, using van Krevelen diagram. The combustion characteristics of HSF were investigated using thermogravimetric analysis (TGA) and ultimate analysis. In addition, the hydrophobicity of fuel is one of the most important issues for utilizing coal, sewage sludge and biomass. Therefore, the hydrophobicity was studied using Fourier transform infrared spectroscopy (FT-IR) and a moisture re-adsorption test.

2. Experimental method and apparatus

2.1. Sample preparation and procedure

HSF, which can replace the sole coal utilization in a coal-firing system, is a 'green fuel' resource. The sewage sludge generated from wastewater treatment plants was first blended with a certain ratio of coal and bioliquid (molasses). The HSF was then treated with a drying and carbonization process to become the green fuel. In terms of commercialization, the detailed manufacturing process for HSF is depicted in Fig. 1. For this study, different kinds of sewage sludge and coal were chosen to evaluate their fuel characteristic. The sewage sludge and coal were dried at 105 °C for 12 h. The coarse dried sewage sludge and coal samples were pulverized in a fan-type disk mill and then separated below 75 μm using an electromagnetic shaker. The separated sewage sludge and coal were mixed and then impregnated with a bioliquid solution at a ratio of 45 wt% (sewage sludge): 45 wt% (coal): 10 wt% (molasses). For the effective diffusion and capillary movement of the bioliquid solution into the sewage sludge and coal pores, they were aged for 24 h and then dried at 105 °C for 6 h. In addition, the synthetic fuels were carbonized to fully eliminate the water and ensure hydrophobicity. The carbonization system principally consisted of a N_2 gas injection part, a carbonization reactor, a temperature controller and a tar trap (Fig. 2). The sample was first injected into the reactor and then the temperature was increased up to 250 °C with a N_2 gas atmosphere. The carbonization reaction for making HSF was maintained for 1 h.

2.2. Analysis technique for verification of fuel characteristics

Three different kinds of coals, namely Indonesian low rank coal (ILRC), Kideco coal (KDCC) and anthracite coal (ATCC), were chosen in various coalification ranges. Sewage sludges, namely Daejeon sewage sludge (DSS) and Hyangnam sewage sludge (HSS), and molasses were used as renewables. The basic properties of the fuels were investigated using proximate analysis (TGA-701 thermogravimeter), ultimate analysis (TruSpec elemental analyzer for C, H and N and SC-432DR sulfur analyzer for S) and caloric value (Parr 6320EF calorimeter). The results are shown in Table 1. To study the combustion characteristics of the fuels, differential thermogravimetry (DTG) was conducted at a heating rate of 10 °C/min and an O_2 flow rate of 100 ml/min, using a Q500 TA Instrument. Additionally, the amount of unburned carbon (UBC) was verified by ultimate analysis. First, the raw sample was heated up to 950 °C with air in an elemental analyzer. Then the combustion reaction was maintained and gases were analyzed for 3 min in order to verify the carbon content of residue sample. The calculation method for UBC is as follows:

$$\mathrm{UBC}\ (\%) = C_{\mathrm{detected\ carbon}}/C_{\mathrm{total\ carbon}} \times 100 \quad (1)$$

where $C_{\mathrm{detected\ carbon}}$ indicates the amount of carbon detected at 950 °C for 3 min using ultimate analysis and $C_{\mathrm{total\ carbon}}$ is the total carbon amount in the raw sample. In order to determine the functional groups of the fuels, FT-IR (Nicolet 5700) analysis was carried out. To compare the hydrophobicity of the fuels under severe conditions, a moisture re-adsorption test was conducted. The respective fuel was injected and stirred in excess water in a vessel for 20 min, and then filtrated using filter paper (< 1 μm) for 10 min. The moisture re-adsorption rate of the fuel was calculated as the difference between the weights before and after water swelling.

3. Results and discussion

3.1. Evaluation of HSF as a fuel

In order to evaluate the characteristics of the HSF when composed of different sewage sludge and coal ranks, proximate analysis, ultimate analysis and caloric value analysis were conducted as shown in Table 2. The caloric value of HSF was greater than that of sewage sludge due to elimination of moisture content and increases in volatile matter and

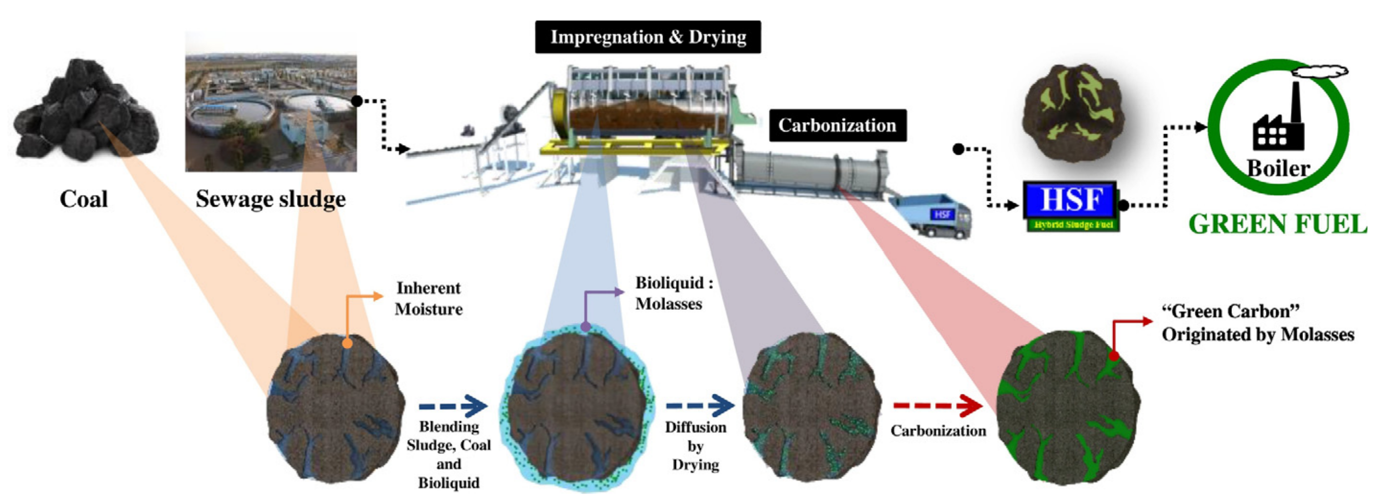

Fig. 1. Schematic diagram of the manufacturing process of HSF.