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Dual bed pyrolysis gasification of coal: Process analysis and pilot test

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ABSTRACT

Via isolating the fuel pyrolysis and char gasification, the so-called dual bed pyrolysis gasification (DBPG) was proposed to realize the co-production of pyrolysis products and gasification gas. The process simulation with Aspen Plus shows that the DBPG process can run autothermally using air as the gasification reagent, but the complete conversion of char in the gasifier requires relatively high O/C ratio due to the absence of steam in the reactor. This would make the higher heating value (HHV) of the produced gasification gas below 1000 kcal/Nm^3. Adding steam to the char gasifier can realize full char conversion at lower O/C ratio to improve the gasification gas quality. The effect of air preheating on the gasification performance was further analyzed to optimize the operating conditions of DBPG. A pilot scale plant (100 kg-coal/h) of DBPG was established and tested by using air as the gasification reagent plant to verify the technology feasibility. At the steady operating temperatures of 600 °C for pyrolyzer and 850 °C for gasifier, the produced pyrolysis gas was rich in hydrocarbons and the tar yield reached 8.4 wt% and was rich in phenols and its derivatives, but the HHV of the gasification gas was only 510 kcal/Nm^3, much lower than the simulated value. A laboratory test on char–air gasification in a fluidized bed reactor further showed that the short residence time of char inside the gasifier and thus the low carbon conversion and the burning of the produced gas in the reactor was the cause for this lower heating value of the gasification gas.

1. Introduction

The coal rich in volatiles, including lignite, subbituminite and bituminite contains high-value chemical structures like aromatic rings. These chemical structures are completely converted into simple molecules of H_2O, CO_2, CO, H_2, and hydrocarbons (C1–C3) in combustion and gasification. It is attractive and promising to extract these valuable chemicals prior to gasification or combustion to produce fine chemicals and fuel oils. For this purpose, the so-called "coal topping" concept was previously proposed in China [1,2]. The coal topping process can be realized in a dual fluidized bed system with its riser of transport bed as the combustor and another bed as the fuel pyrolyzer (see Fig. 1a). Between the two reactors, the heat carrier particles (HCPs), which are usually coal ash blended with char, are circulated to carry heat from the riser combustor of char to the coal pyrolyzer to supply the pyrolysis-needed endothermic heat.

For the dual bed coal topping process, the moving bed [3,4], downer [5,6] and fluidized bed [7–9] have been tested as the coal pyrolyzer. Liang et al. [3] investigated tar yield in a lab-scale moving bed pyrolyzer integrated into a circulating fluidized bed (CFB) combustor system, finding that the maximal tar yield was up to 11.0 wt% for Shenmu bituminite in dry coal basis using quartz sand as the HCPs at 850 °C. Then a pilot poly-generation plant was built from retrofitting a 75 steam-t/h CFB boiler through combining a moving bed coal pyrolyzer with its combustor, and the test of this plant realized a tar yield of 6.0 wt% (dry coal base) at 600 °C for the same Shenmu coal [4]. Wang et al. [5] conducted coal pyrolysis in a downer reactor coupled with a riser combustor (coal treatment capacity was 8 kg/h) and found that the optimal pyrolysis temperature was 660 °C and a tar yield of up to 14.5 wt% was obtained for a kind of pulverized subbituminous coal below 280 μm. Zhu et al. [6] investigated the effect of coal particle size on pyrolysis and char reactivity in the downer reactor, showing that increasing the particle size raised the char yield but decreased char reactivity. A downer coal pyrolysis process coupled to a 75 steam-t/h CFB boiler was also built in Hebei province of China, and a preliminary test showed a satisfactory process performance and the further optimization for the performance is still under way. For developing the dual bed "coal topping" process with a fluidized bed pyrolyzer, Zhang et al. [7] investigated the pyrolysis of a Chinese subbituminous coal in 4–6 mm in a laboratory fluidized bed reactor and found that the maximal pyrolysis oil yield occurred at 600 °C and the required residence time of coal particles in the bed should be over 3 min. The

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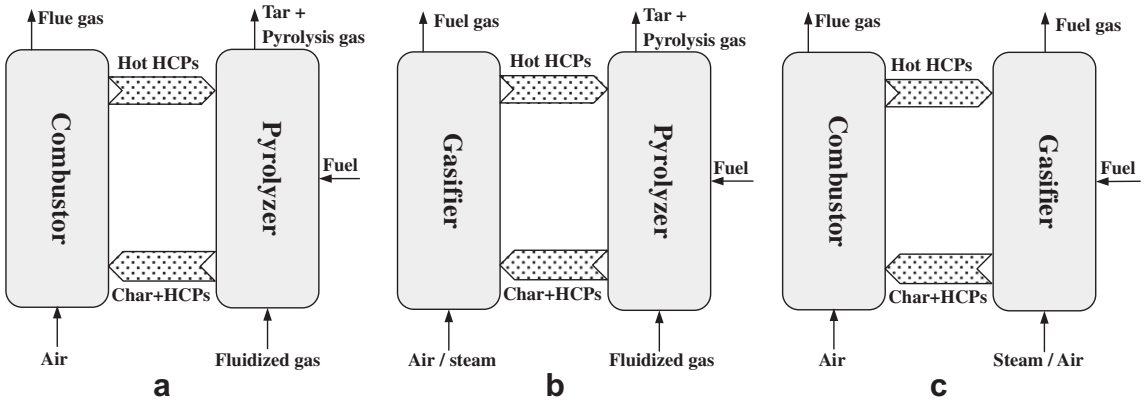

Fig. 1. Conceptual diagrams of technical processes of (a) coal topping (or dual bed pyrolysis combustion), (b) dual bed pyrolysis gasification (DBPG) and (c) dual fluidized bed gasification (DFBG).

study of Xiong et al. [8] in the same reactor further found that the highest tar yield appeared at 550–700 °C for coals from lignite to bituminite. They for the first time demonstrated that the use of coal ash as the bed material decreased evidently the yields of tar and gas, but adopting the gas simulating the coal pyrolysis gas composition as the reaction atmosphere facilitated conversely the tarry liquid production. Fang et al. [9] studied the pyrolysis of Huainan bituminous coal in a fluidized bed pyrolyzer integrated with a 75 steam-t/h CFB combustor and found that the polygeneration system could run continuously and steadily with tar yield of 11 wt% at about 540 °C of pyrolysis and the usual combustion temperatures in the char combustor.

The preceding coal topping has so far referred to the process illustrated in Fig. 1a exclusively, which is based on the integration of the isolated coal pyrolysis with char combustion. It can thus be called the dual bed pyrolysis combustion (DBPC). From the application aspect, this implicates the retrofit of CFB boilers so that the coal chemical structures can be extracted to produce high-value chemical products before the complete combustion of the coal. Extending this reaction decoupling principle to the gasification process in CFB-type reactors [10], we have proposed the dual bed pyrolysis gasification (DBPG) process characterized with the integration of the isolated coal pyrolysis with char gasification [8], as illustrated in Fig. 1b. This newly devised DBPG process intends to extract the coal-inherent liquid and gas components in volatiles before the through gasification of coal into CO, CO_2 and H_2.

As a coal pyrolysis process, the performance of the DBPG should be similar to that of the DBPC highlighted in the second paragraph shown above. As a coal gasification process, the DBPG should be compared to the well-documented dual fluidized bed gasification (DFBG) illustrated in Fig. 1c. According to Zhang et al. [10], the DFBG is featured with the isolation of the char combustion reaction that generates the endothermic heat required by the reactions of fuel pyrolysis and gasification occurring in another integrated reactor (see Fig. 1c). The fundamentals and process characteristics of DFBG have been extensively investigated in the community to show its merit of producing middle caloric fuel gas without recourse to the use of O_2-rich gasification reagent and its particular suitability for highly reactive fuels like biomass and lignite [11–15]. Against the DFBG, the newly proposed DBPG conceptualized in Fig. 1b may take rather more attractive advantages as following:

(1) The DBPG allows the co-production of pyrolysis liquid and gasification gas to realize value-added hierarchical utilization of coal. This realizes actually the similar co-production effect as Lurgi gasifier but for powder coal and also easier to recover the tar product as clarified below.
(2) The tarry matters present only in the gaseous pyrolysis product, which greatly facilitates the tar recovery operation and reduces the load of gas cleaning. For the processes like Lurgi gasifier and DFBG, the tarry matters present in the large-volume gasification gas, raising thus the load of gas cleaning.
(3) The DFBG may require flue gas cleaning system such as desulphurization and denitration in addition to the gasification gas cleaning. For DBPG, however, the gas cleaning is only for the gasification gas that may be mixed with the pyrolysis gas after its recovery of liquid tar.
(4) The oxygen consumption for DBPG should be lower than in DFBG because the effluent temperatures of the pyrolysis product are lower than that of the gasification gas in the DFBG.
(5) In DBPG the isolation of coal pyrolysis and char gasification creates the circumstance of gasification without the presence of pyrolysis gas around the char particle, to facilitate thus the char gasification [16,17].

With the foregoing technical advantages, the DBPG would appear to be a promising new gasification technology that may have great potential applications for the production of fuel gas as the Lurgi-type or CFB-based gasifiers. With the intention of demonstrating the feasibility of this newly proposed technology, this study performed first a process simulation using Aspen Plus to clarify the heat and mass flow features and the performance characteristics of the technology. In turn, a pilot test at the capacity treating about 100 kg/h coal was conducted to further show the technology feasibility and process characteristics. Thus, it hopes to not only verify the rationality of the new DBPG technology but display also the conception of hierarchical conversion and value-added utilization of coal in gasification processes.

2. Experimental section

2.1. Process simulation

The Aspen Plus model used to simulate the dual bed pyrolysis gasification (DBPG) process is shown in Fig. 2, which consisted mainly of the modules for coal pyrolysis and char gasification. The supplementary parts around such two modules included the elements decomposer for fuel, gas–solid separator (cyclones), heat exchanger, gas–liquid splitter and mixer. Coal was first broken into its elements (H, C, O, N, S), ash and water as its moisture in the decomposer and then was heated up to 600 °C by mixing with

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