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Characterization and pilot scale test of a fluidized bed two-stage gasification process for the production of clean industrial fuel gas from low-rank coal

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ABSTRACT

To utilize low rank coal efficiently, a fluidized bed two-stage (FBTS) gasification process, mainly consisting of a FB pyrolyzer and a transport FB (TFB) gasifier, has been proposed for the production of clean fuel gas. To verify the feasibility and technical features of this novel gasification technology, a pilot autothermal platform, with a treating capacity of 100 kg/h for coal, was designed and built up. By adopting a kind of lignite from Inner Mongolia, the running state and fuel gas quality were compared systematically under typical operational conditions. The results show that by keeping the reaction temperatures of pyrolyzer and gasifier at around 840 °C and 1000 °C, respectively, the corresponding tar content in fuel gas at the outlets of pyrolyzer and gasifier were 1127 mg/Nm^3 and 365 mg/Nm^3, reaching a high tar removal efficiency. Under the stable operation state, the volume fractions of CO, H_2, CH_4 and CO_2 in fuel gas were 14.4%, 8.3%, 3.4% and 11.3%, respectively, and the corresponding higher heating value of fuel gas was about 1100 kcal/Nm^3. Compared with the tar from pyrolyzer, the heavy oil fraction in tar from gasifier reduced significantly, while the light oil components increased sharply simultaneously, showing significant effect of catalytic reforming by hot char bed on tar removal.

Introduction

Among numerous coal utilization technologies, gasification represents one of the most promising and competitive option because of cleanness and high-efficiency [1–3]. By gasifying carbon-containing fuel, it can mainly produce fuel gas and syngas, which are widely used for heat, electricity, high-value added chemicals, and so on. For syngas gas, the commonly adopted gasification processes, including BGL, Lurgi, Texaco, Shell, GSP and so on, are characterized by large scale, high temperature, high pressure, expensive investment, and oxygen enriched operation [4–6]. For fuel gas, at present, it usually adopts the atmospheric pressure fixed bed gasifier or fluidized bed gasifier [7,8], still having a big gap to the requirement of large treating capacity, low investment and atmospheric pressure operation. Compared to the fixed bed gasifier, fluidized bed gasifier is more attractive and economical, especially in the items of temperature and pressure distributions, treating capacity, feasibility in pulverized coal (<10 mm) and investment [9,10]. However, due to low operating temperature and using air as gasification agent, the high tar content in fuel gas becomes a great challenge for fluidized bed gasification technology.

As we know, tar is an undesirable but inevitable liquid by-product in gasification under low and medium temperature operation. Below its dew point, tar quickly condenses, and thus brings about many operational and environmental problems, such as clogging pipeline, eroding equipment, poisoning catalyst, causing large amount of phenol-containing wastewater, and so on [11,12]. The existing tar removal technologies can be generally categorized into primary method and secondary method. The primary method means tar removal in gasifier, mainly including optimization of operating parameters, adoption of catalytic bed material, and modification of gasifier structure, while the secondary method refers to gas cleaning treatment outside the gasifier, such as physical treatment, thermal cracking, plasma-assisted cracking, catalytic reforming, etc. [13–16]. Generally, from primary method, the initial tar content can be reduced greatly, which is very beneficial to further elimination by secondary method.

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As an exception, staged gasification technology is viewed as a good choose of primary method for tar removal in gasifier characterized by separating the fuel gasification process into two subprocesses (namely, fuel pyrolysis and char gasification) at different but connected reactors [17–19]. A respective biomass two-stage gasification technology was developed by Technical University of Denmark, consisting of an upstream screw pyrolyzer and a downstream fixed bed gasifier [20,21]. Passing through the hot char bed in gasifier, the tar produced in pyrolyzer can be thermally cracked and catalytically reformed to non-condensable gas components, such as H_2, CO, CO_2, CH_4, and so on, realizing the control of tar emission successfully. Inspired by the decoupling concept, Zeng et al. [22] developed another two-stage gasification process for pulverized coal (particle size below 10 mm), mainly consisting of a fluidized bed pyrolyzer and a fixed bed gasifier. On a pilot plant, the tar content at the outlet of gasifier was controlled at the level of below 300 mg/Nm^3. Both of the two processes mentioned above verified the good catalytic activity of char on tar and the feasibility of staged gasification in fuel gas production. However, some limitations, such as large pressure drop, difficult in scale-up and poor flexibility in pulverized feedstock, still prevent the wide application of staged gasification in large scale [10,23].

For the clean production of fuel gas from pulverized coal, a novel fluidized bed two-stage (FBTS) gasification technology has been proposed based on decoupling method by the Institute of Process Engineering (IPE), Chinese Academy of Sciences (CAS). As illustrated in Fig. 1(a), this process is mainly composed by a fluidized bed (FB, the first stage) pyrolyzer and a transport fluidized bed (TFB, the second stage) gasifier [24]. In the pyrolyzer, coal is heated quickly by high-temperature heating carrier from cyclone separator, and then begins the reactions of pyrolysis and/or partial gasification. The spent heating carriers and all the products from pyrolyzer, including pyrolysis gas, tar and char, are overflowed into the TFB gasifier for char gasification and fuel gas improvement. The released tar from the pyrolyzer will be catalytically converted into non-condensable gas components by hot char in the TFB gasifier [25,26]. The unreacted char residues and heating carriers can be captured by cyclone and returned into the pyrolyzer by a refeeding valve. Due to synergizing the merits of FB and TFB reactor, the newly proposed FBTS gasification process is suitable for treating pulverized feedstock on an industrial scale for clean fuel gas production with low tar emission.

Here, it is worthwhile to compare the FBTS and dual fluidized bed (DFB) gasification technologies [27–29]. As illustrated in Fig. 1, generally, both of the two technologies consist of fluidized bed reactor and transported bed reactor. For the former, the two fluidized bed reactors are used as pyrolyzer and gasifier, respectively. The produced tar from pyrolyzer will be catalytically reformed in gasifier by hot char bed in gasifier, thus lowing tar content in fuel gas. While for the latter, the two fluidized bed reactors are used as gasifier and combustor, the generated tar-containing fuel gas flows out the gasifier directly, inevitably leading to higher tar content. To understand more clearly, the main differences between the FBTS and DFB gasification process are further tabulated in Table 1.

According to our previous laboratory researches [22,30], a pilot plant adopted to the newly proposed FBTS gasification process has been designed and built with a treating capacity of about 100 kg/h. A kind of lignite was used to gasify on this platform to simulate the practically possible conditions of fluidized bed two-stage process. In terms of promoting gasification process and eliminating tar generation, the process feasibility and technical feature will be verified, which is very beneficial to guide the further design and scale up of this process.

Experiments

Fuel and bed material

The coal sample adopted in this study was a kind of lignite from Inner Mongolia of China, whose proximate, ultimate and ash analysis were listed in Table 2. From it, one can see clearly that the con-

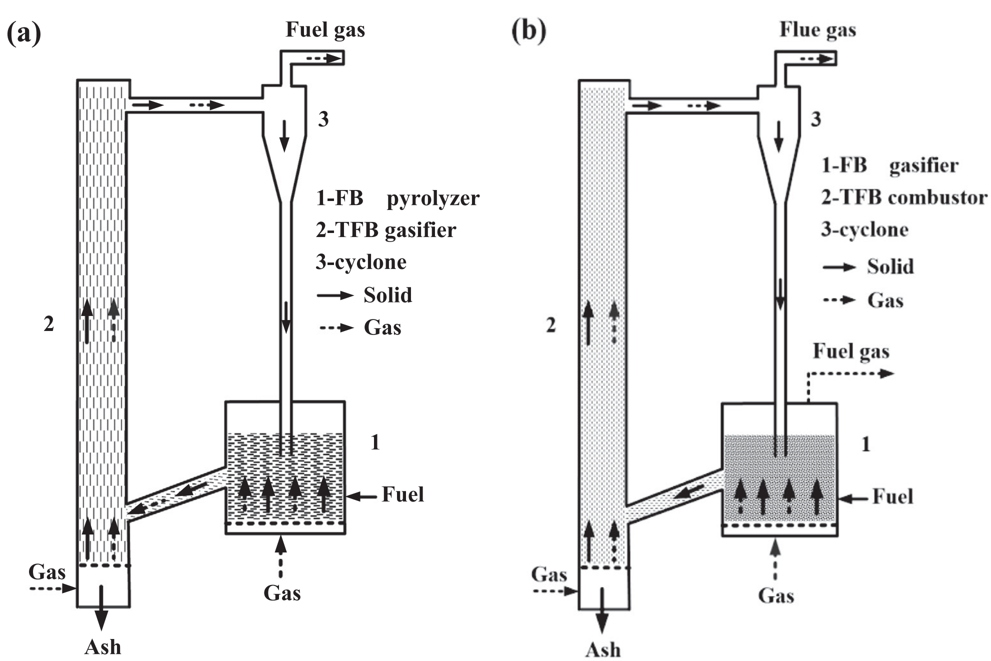

Fig. 1. Conceptual diagrams of the new FBTS (a)* and DFB (b)# gasification process. *Gases for FB pyrolyzer: N_2/air/steam; gases for TFB gasifier: CO_2/Air/O_2/steam; #Gases for FB gasifier: CO_2/air/O_2/steam; gases for TFB combustor: Air/O_2. 1-fan, 2-ash tank, 3-coal, 4-hopper, 5-screw feeder, 6-pyrolyzer, 7-overflow pipe, 8-gasifier, 9-cyclone, 10-loopseal, 11-sampling pipe, 12-primary heat exchanger, 13-secondary exchanger, 14-water, 15-water tank, 16-cyclone, 17-fly ash, 18-incinerator, 19-bag filter, 20-draught fan, 21 chimney.

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