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Jetting pre-oxidation fluidized bed gasification process for caking coal: Fundamentals and pilot test

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HIGHLIGHTS

- A novel JPFB gasification process has been proposed to treat caking coal.
- The reasonable operating conditions were determined by the fundamental study.
- By decoupling pyrolysis and gasification, the produced tar will be removed easily.
- The pilot test fully demonstrated the feasibility of the JPFB gasification process.

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ABSTRACT

A new jetting pre-oxidation fluidized bed gasification (JPFBG) process, mainly consisting of jetting pre-oxidation zone and char gasification zone, has been proposed and developed by Institute of Process Engineering (IPE), Chinese Academy of Sciences (CAS) to utilize cohesive washing middling coal effectively for fuel gas production and thus replacing the valuable coke oven gas. This article is devoted to summarizing the results obtained in the fundamental studies and a pilot plant. The fundamental studies conducted on an externally heated laboratory JPFB gasification setup demonstrated that the appropriate operating conditions for the pre-oxidation zone and the char gasification zone were at temperature of 950 °C with an excessive air ratio (ER) of about 0.13, and at temperature of 1000 °C with an ER of 0.17 and a mass ratio of steam to coal of 0.09, respectively. Based on these condition data, an autothermal pilot system with a treating capacity of 150 kg/h for strong cohesive coal was built and tested to demonstrate the JPFB gasification process. Keeping the temperatures of the pre-oxidization zone and char gasification zone at about 950 °C and 1000 °C respectively, the higher heating value of the produced fuel gas was close to 4000 kJ/N m^3. The obtained typical results from the continuously steady operations of the pilot plant fully verified the technical feasibility and clarified the technical features of the tested new JPFB gasification process.

1. Introduction

China has become the largest coke producer in the world since 1993 [1]. For the conventional coke oven adopted in coking process, as shown in Fig. 1(a) [2], it needs to combust about 50% of the produced coke oven gas (COG) to maintain the required reaction temperature [3,4]. Due to the good gas compositions and quality listed in Table 1, coke oven gas is a good chemical resource to produce other high value-added chemical, such as synthetic natural gas, methanol, and high-purity H_2 [5–7]. So, direct combustion of COG for supplying heat in the coking process is not a very efficient and effective method. A promising route is replacing the COG by another lower value of fuel for the combustion chamber.

On the other hand, in the washing process for the coking coal, it will produce a great deal of middling coal, amounting about 30–40 wt.% of the total quality of raw coal. Now, in China, a few part of the middling coal is used to directly combustion for electric power, heat and so on. And the rest of large number of middling coal is stacked around the plant, leading to serious resource waste and environmental pollution. So, a potential technical route has been proposed, as illustrated in Fig. 1(b). The middling coal is gasified to produce industrial fuel gas for firing and supplying heat for the coke oven, which thus can replace the COG to produce the high value chemicals. The new technical route not only raises the total utilization value of resources, but also reduces the potential

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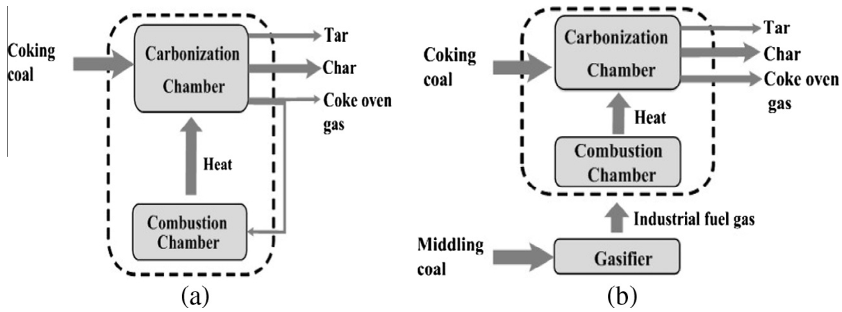

Fig. 1. Conventional (a) and new (b) structure of coke oven.

Table 1
Typical gas compositions of COG in coking process.

	H_2	CH_4	CO	CO_2	N_2	C_2H_4	C_2H_6	C_3H_6
Composition (vol.%)	55–60	23–27	5–8	1–2	3–7	1–2	0.5–1	0–0.5

environmental pollution. However, considering the property of middling coal, such as high content of ash, low volatile matter, low reactivity, and strong cohesiveness, the key problem in the new route is still how to gasify the middling coal economically and efficiently.

Up to now, a huge amount of gasification technologies have been developed successfully, which are usually categorized into fixed bed/moving bed gasification, fluidized bed gasification and entrained flow gasification according to the structure of reactor [8–11]. For the production of coal-based industrial fuel gas in China, fluidized bed gasification is more attractive and economical, due to the advantages, such as large treatment capacity, wider particle size distribution for power coal (<10 mm), low tar generation, and low capital investment [12]. The representative gasifiers include Winkler gasifier, high-temperature Winkler gasifier, Enda gasifier, U-gas gasifier, Kellogg Rust Westinghouse (KRW) gasifier, ash-agglomeration fluidized bed gasifier and so on [13]. Among these gasifiers, only KRW gasifier has the ability to treat caking coal because of its unique nozzle feeding system. However, from the point of practical operation, it is still difficult to run very steadily, perhaps mainly because of the difficulty of ash agglomerating technology. Moreover, the consumption of fuel gas for recycling gas in this technology is relatively large.

To gasify washing middling coal and other strong caking coal, a new jetting pre-oxidation fluidized bed gasification process (JPFB) schematically illustrated in Fig. 2 has been proposed by Institute of Process Engineering, Chinese Academy of Sciences, which allows clean and economic production of coal-based fuel gas [14]. The new JPFB gasifier mainly consists of jetting pre-oxidation zone and char gasification zone. The caking coal particles, with particle sizes below 6 mm, are transported by air with very high speed in the feeding pipe and then jetted instantaneously into the dilute phase zone of gasifier, where they are dispersed and pyrolyzed fully at high temperature and O_2-containing atmosphere. The formed viscous and plastic matter on the surface of the coal particles will be oxidized and destroyed, making coal lose its caking propensity. The produced chars fall into the dense phase zone of the gasifier and then began to gasify with oxidation agent. Compared to feeding coal by a screw feeder adopted in the gasifiers including HTW, Ende, U-gas, AFB and so on, the jet feeding in O_2-containing gas adopted in the JPFB process can destroy the coal caking property by not only the pre-oxidation effect but also the enough dispersion of the coal particles in the pre-oxidization zone. Compared to the KRW gasifier, for preventing ash melting in the JPFB process, the gasification temperature will be controlled below the coal ash melting point. Due to decoupling coal pyrolysis and char gasification, the inhibition effects of pyrolysis gas on char gasification, which commonly exist in the FB gasifier [15], can be also prevented well in the JPFB gasifier, making the higher gasification reactivity for the produced char. Moreover, at the bottom gasification zone, to strengthen char gasification, the required amount of oxygen-enriched air and steam will be much smaller.

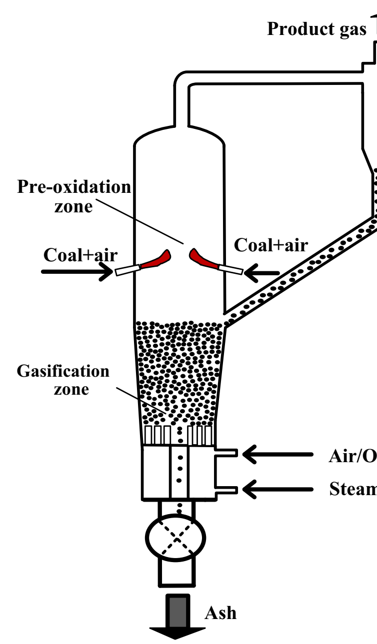

Fig. 2. Conceptual diagram of the proposed jetting pre-oxidation gasification technology.

In the previous study, the effect of jetting pre-oxidation technology on the destruction of coal caking property, including reaction temperature, excessive air ratio (ER), O_2 concentration in the pre-oxidation zone has been systematically studied. The operational conditions for fully destroying the caking propensity of the tested coal were at temperature above 950 °C, and ER above 0.1 [16,17]. Then, one pilot-scale plant was built and several tests were carried out to validate the technical characteristics by gasifying a mixture of bituminous coal and washing middling coal. However, some key problems are still not clear and needed to be researched further. One is the gasification behavior of char resulted from the pre-oxidation zone. Another is the technical feasibility and advantages for the strong coking coal.

On the basis of our previous fundamental studies, in the present study, to simulate the practically possible conditions for the process in Fig. 2, a laboratory JPFB reactor with continuous feeding