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Pilot-scale comparison investigation of different entrained-flow gasification technologies and prediction on industrial-scale gasification performance

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HIGHLIGHTS

- The performance of pilot-scale entrained-flow gasifier was investigated.
- Effects of coal property, feeding mode and gasifier lining type were discussed.
- The performance of industrial-scale gasifier was predicted through simulation.

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ABSTRACT

Effect of the coal property, the coal feeding mode (coal-water slurry (CWS) or dry coal powder (dry feeding)) and the gasifier lining type (refractory brick wall or membrane wall) on the performance of pilot-scale entrained-flow coal gasifier with a throughput of 30 tons of coal per day was systematically investigated. Based on the pilot plant results, the impact of coal type, coal feeding mode and the gasifier lining type on the coal gasification process was analysed quantitatively. Moreover, through simulation, raw material consumptions with different combinations of feeding mode and lining type for commercialized gasifiers were predicted, which provides useful information in choosing a suitable gasification technology and the optimization of coal gasification process.

1. Introduction

Gasification is a technological process that is conventionally employed to convert the solid feedstocks, such as coal, petcoke or biomass, into clean syngas consisting primarily of hydrogen and carbon monoxide [1]. In the gasification process with coal as feedstock, coal breaks down in the presence of steam and oxygen at high pressure and high temperature to form the desired gaseous product. Characterized by fast reaction rate, high carbon conversion, large throughput and high efficiency, the most applied reactor for coal gasification is of the entrained-flow gasifier which has been widely employed in chemical and energy industrial fields, such as manufacturing chemical fertilizer, methanol, olefins, oil and SNG [2–4]. In the matter of saving energy and reducing raw material consumption, it is important to choose a suitable gasification technology and operation condition on the basis of raw material characteristics and product requirements.

Generally, the entrained-flow coal gasification technology can be classified by the coal feeding mode and the lining type of the gasifier chamber. Coal can be delivered into a gasifier as coal-water slurry (CWS) [5] or pulverized coal [6]. Two types of lining, either refractory brick wall [7] or water-cooling membrane wall [8] can be used in the gasifier chamber to protect the steel walls. It is clearly that the different coal feeding mode and the type of gasifier lining, or their different combinations, can lead to different performance of a gasifier. However, quantitative understanding of their impacts on the gasification process is scarce due to the lack of available data from the experimental or semi-industrialized investigation especially at different gasifier settings and coal feeding mode.

In this paper, the effects of feedstock state and lining type on the performance of entrained-flow coal gasification were

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Nomenclature

q	water mass flow rate, kg/s	Q	low calorific value, kJ/kg
c_p	specific heat capacity of water, kJ/(kg K)		
Δt	temperature difference, K	*Greek symbols*	
m	feeding rate of coal, kg/s	η	heat loss, %

investigated through the pilot-scale process technologies based on various combinations of coal feeding mode and lining type. The pilot-scale test results provided not only the quantitative comparison of the performance of the gasifiers at various combinations of coal feeding mode and lining type but also the further insight into the entrained-flow coal gasification technology in industrialized scale.

2. Pilot plant

2.1. Gasification process

The pilot-scale coal gasification process is shown schematically in Fig. 1 which consists of three subdivisions, i.e., (1) coal feeding unit, (2) gasification unit, (3) syngas scrubbing and dust removal unit [9].

Tests in the pilot-scale gasifier were carried out by using two types of feedstock, i.e., CWS and dry coal powder (dry feeding). CWS was pumped into the burner of a gasifier while the oxygen jet (at the velocity of about 120 m/s) around the exit of the burner atomized the CWS into droplets at micron-meter level. Subject to high temperature and high pressure, droplets experienced a series of physical and chemical changes such as evaporation, pyrolysis, combustion and gasification in the gasifier. As to the dry feeding mode, the pulverized coal was transported pneumatically by N_2 or CO_2 to the gasifier, where the coal powder reacted with the oxygen and steam at the desired temperature and pressure [10]. The oxygen jet spurted out at the velocity of about 60–80 m/s, much lower than that for slurry feeding, due to the property of well dispersion of the dry powder itself.

The syngas produced at high temperature together with the molten slag left the gasification chamber and immediately entered a quench bath, where the syngas was bubbling through the water while the coarse slag fell to the bottom of the bath. The syngas after quench was fed into a scrubber for dust removal.

2.2. Gasifier

The gasifier was featured with four opposed-impinging jetting burners and consisted of a gasification chamber and a quench bath. In this paper, two types of lining wall were adopted in the gasification chamber, i.e., the refractory brick wall and the water-cooling membrane wall. The gasification chamber was a cylinder-shaped reactor. For the refractory brick-lined chamber, its inner diameter was 900 mm and the height was 4276 mm; for the membrane wall-lined chamber, it had an inner diameter of 650 mm and a height of 2700 mm.

The refractory lining was typically made up of three layers of refractory bricks of different materials with desired properties in order to obtain good thermal insulation. Such lining structure can significantly reduce the heat loss. However, subjected to corrosion by molten slag and scour by high temperature gas stream, the refractory brick wall would be damaged at various degrees, and has to be replaced locally or wholly after scheduled operation period. For the membrane wall-lined gasifier, water as cooling agent flowed through the tubes to remove the heat from gasifier. Meanwhile, the molten slag that deposited over the wall surface formed a slag coating, which consisted of a liquid layer, a plastic layer and a solid layer [11–13]. As the result, the membrane wall is protected from being damaged by high temperature because of the great thermal resistance of the slag coating. In this sense, the membrane-lined gasifier can bear temperatures as high as 1600–1700 °C.

It should be noted that the gasification temperature mentioned in this paper refers to the exit temperature of the chamber, which can be calculated through the gasification reactions.

2.3. Coal properties

Four types of coals, Beisu, Baodian, Nantun and a coal blended coal, were used as feedstock in the pilot-scale test. The blended coal was prepared for CWS feeding while the other three coals were prepared for dry feeding powder. Properties of these four types of coals are listed in Table 1.

The coal analysis indicates that the blended coal and Beisu coal both have lower ash fusion temperatures (FT) of 1210 °C and 1274 °C, respectively. Baodian coal has a FT of 1435 °C and Nantun coal the highest FT of 1534 °C. For the purpose of smooth slag-off at a relative low gasification temperature to reduce the raw material consumption, the Nantun coal was then blended with limestone up to 3% (wt.) to reduce its FT to 1360 °C [14,15].

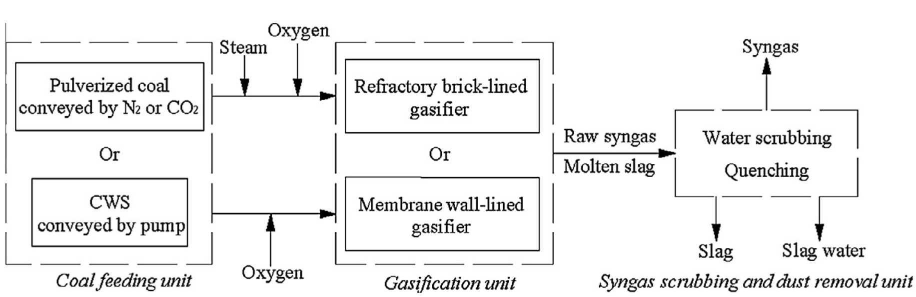

Fig. 1. Flowsheet of entrained-flow coal gasification process.