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Experiment study on entrained flow gasification technology with dry slag by second-stage water supply

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ABSTRACT

Experimental system of a new entrained flow gasifier with second-stage water supply (20 kg/h) was set up in this paper, and effect of molar ratio of O/C on temperature distribution, syngas composition, carbon conversion and effective syngas were analyzed with a typical high AFT coal (Guizhou LJ coal). The results of non-second-stage water and second-stage water with changing molar ratio of O/C indicate that, when the molar ratio of O/C is larger than 0.96, gasification efficiency with dry slag by second-stage water would become better than non-second-stage water. Specifically, when the molar ratio of O/C was 1.1, the effective syngas fraction and carbon conversion of second-stage water gasification were 80.2% and 93.24% respectively. Correspondingly, the effective syngas fraction and carbon conversion of non-second-stage water gasification were 78.5% and 91.67% respectively. Furthermore, the gasification temperature was lower than the ash fusion temperature of test sample, the slag was non-melt during all the gasification experiments. The optimal gasification was conducted with the process temperature under 1450 °C, which was lower than the ash fusion temperature of LJ coal. These experimental results prove the applicability of entrained flow gasification technology with dry slag by second-stage water supply on using high AFT coals, which is helpful to generalize the large-scale gasification technology using abundant high AFT coals in China.

1. Introduction

Entrained flow gasification technology is widely employed in chemical and energy industrial fields, such as manufacturing chemical products and IGCC power generation technology [1,2] in China. Due to the highly efficient and clean carbon conversion process, large-scale pressurized entrained-flow gasification has been considered as a crucial technology for clean coal utilization [3,4]. In recent years, research on entrained flow gasification with high ash fusion temperature (AFT) coals has been conducted gradually due to abundant high AFT coals deposits in China [5–7].

Generally, based on the coal feeding mode, the entrained flow coal gasification technology can be divided into coal water slurry (CWS) gasification and pulverized coal gasification. Both of the two type gasification technologies are widely employed in industry. In comparison with pulverized coal gasification [8], CWS gasification can obtain higher volume fraction of H_2 composition in the syngas [1]. In addition, the preparation of CWS is more complex but the transport of CWS is more stable [9]. The process temperature of CWS gasification can be adjusted with the oxygen injection, but usually would not exceed 1400 °C at the outlet of the gasification reactor [10]. Nowadays, mainly entrained flow gasification prefers coals with low ash content and low AFT (below 1400 °C) to achieve steady slag tapping, because they have appropriate slag viscosity during that temperature [11]. When the high AFT coals (especially for the AFT higher than 1500 °C) should be used as the fuel of entrained flow gasification technologies [1,3,4,8], it is impractical to simply introduce more O_2 to raise the operation temperature because the tolerable temperature of refractory brick or membrane in gasifier is limited. Thus, blending with the low AFT coals or other additives to reduce the FT is generally acceptable. However, it is easy to generate non-melting slag due to wrong blending ratio in industrial production. Besides, the cost of additives is usually expensive.

Based on our research, a new idea is presented to solve the problem on entrained flow gasification with high AFT coals. Under the condition of oxygen needed to keep the high efficiency gasification, by adding two opposite nozzles as second stage O_2/H_2O injection, the oxygen injection by the primary nozzle is properly allocated. Reducing the oxygen injection from the primary nozzle, the regional violent combustion near the primary nozzle will be moderated and the temperature will be lowered, with the result that the coal ash would not melt. As a result of oxygen classification and water injection, the temperature during gasification process was lower than the AFT of using coal and the slag was solid when it was expelled from the gasifier. In detail, the gasifying agent refers to O_2 and H_2O, the specific composition and proportion of them

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depend on the gasification situation, coal type, syngas composition requirements, etc. The second-stage O_2/H_2O injection can greatly improve the flow field disturbance effect of the gasifier reactor. Tests and simulations of the flow field distributions in a cold model entrained flow gasifier have been conducted with different injecting velocity, position, number of nozzles. The results demonstrate that the flow field distributions in the gasifier would be greatly improved due to more reflux gas forming by two-stage O_2/H_2O injection [12]. Furthermore, the gasification reaction would be enhanced with the strong gas transfer in the boundary layer of the char particle caused by two-stage O_2/H_2O injection under high temperature.

In this paper, based on other studies on the entrained flow gasification experiments [13–17], a 20 kg/h entrained flow gasifier with dry slag by second-stage water supplying (EGDSSW) was established, and experiments were conducted under 8 different operating conditions, 4 with second stage gasifying agent injection and 4 without. In this study, the second stage gasifying agent with oxygen atom refers to water only due to safety issues and equipment constraints. The experiments with second stage O_2/H_2O supply would be presented in next work.

2. Experimental apparatus and procedure

2.1. Coal water slurry preparation

The entrained flow gasification technology with dry slag by second-stage water supplying was particularly for coals with high ash fusion temperature (AFT), therefore the Guizhou LJ coal (ash flow temperature above 1500 °C) was used in this experiment.

The LJ coal was pulverized with a high speed ball mill and mixed with deionized water containing the additives [18,19], the loading of coal reached to 65% in the CWS. The mean diameter of the coal particles was approximately <50 μm.

The proximate analysis, ultimate analysis, ash composition analysis and ash fusion characteristic data of LJ coal were presented in Table 1.

2.2. Experimental apparatus and procedure

In this study, the entrained flow gasifier with dry slag by second-stage water supply (EGDSSW) was designed, constructed, and operated. The work of EGDSSW started in 2013, and the objective was to provide valuable information and optimal operating parameters for the entrained flow gasification technology with dry residue by second-stage water supply using typical high AFT coal. A schematic of the EGDSSW system was presented in Fig. 1.

The EGDSSW consists of an alumina-based refractories lined reactor (0.46 m in inner diameter and 2 m in vertical reactor wall length) with a conical shaped outlet followed by a water sprayed quench chamber for syngas cooling and gas/solid-residue separation. The process temperatures in the reactor are recorded by five thermocouples placed vertically inside the reactor, which are shielded by protective ceramic encapsulation. Three thermocouples were mounted in the combustion and gasification reaction region (upper part) of the reactor, two thermocouples were mounted in the gasification reaction region (lower part) of the reactor.

Table 1
Main properties of high AFT coal A.

Coal type	Proximate analysis, %				Ultimate analysis, %				
	Mad	Aad	Vad	FCad	Cad	Had	Oad	Nad	Sad
LJ coal	2.49	13.00	31.99	52.52	73.28	4.52	4.32	1.36	1.03
	Composition of ash %								
	SiO_2	$Al_2O_3$333	$Fe_2O_3$3	CaO	MgO	Na_2O	K_2O	TiO_2	SO_3
LJ coal	53.96	30.23	5.77	2.87	0.89	0.37	0.64	2.92	1.62
		Ash fusion temperature, K						Qnet,ar, (kJ/kg)	
		DT	ST		FT				
LJ coal		1703	>1773		>1773			28,530	

The coal water slurry (CWS) was stirred in an agitation tank at least for 1 h before experiment, and kept stirring during the experiment proceeding. The CWS was transported by a screw pump and introduced in the top of the reactor. The mass of CWS was controlled by the frequency of the pump (from 1– 50 Hz) and calibrated for 20 min at certain frequency repeatedly. To ensure the CWS was transported as a liquid to the top nozzle, cooling water was flowed through a concentric vertical tube near to the primary nozzle. The first stage oxygen was evaporated in a liquid oxygen evaporator and introduced in the top of the reactor with the CWS. The accuracy of oxygen flow was controlled by a MFC and adjusted by a ball valve. The second stage water was introduced by two opposed nozzles located 0.5 m from the top of the reactor, the deionized water was controlled by a double plunger metering pump. To ensure the opposed nozzles closed in a safe condition, a stream of N_2 was flowed constantly through a supply pipe that surrounded them into the reactor. The N_2 came from a group of nitrogen cylinders (with 99.99% N_2) and controlled by a MFC.

Prior to beginning the reaction process, the reactor was heated by diesel fuel and air, which was introduced in the top-end of the reactor. The two nozzles were symmetrical and titled toward the center axis of the reactor. Meanwhile, the diesel and air was separately controlled by a turbine flowmeter. The temperature in the reactor increased rapidly to reach approximately 1000 °C (nearly 1 h), then the mass flows of diesel and air were decreased to warm the reactor uniformly (nearly 1 h). After that, the diesel was cut off, and a small amount of N_2 replaced the air to cool the diesel nozzle. The gasification process started by feeding the CWS and first stage oxygen, and then the second stage water was added to cool the reaction temperature and enhance the blending the reactants. The raw syngas, cooling N_2 and other particulates (mainly ash and char) were cooled by cooling water in the water quench vessel resulting in exit gas temperatures below 100 °C. Henceforward, the purged raw syngas was bubbled through the chimney to leave the gasifier. In order to measure the volume concentration of the exit gas (mainly CO, CO_2, CH_4 and H_2) of raw syngas, a gas analysis meter (Gasboard 3100) was used after a two-step filter. After gas sampling, the produced syngas was collected to study for CO_2 absorption and capture or burned out by a small burner. When the experiment was over, the particles (ash and char) were sampled from the black water flowing out at the bottom of the gasifier. The carbon conversion was derived using a Thermogravimetric Analyzer (TGA) with the particles samples.

2.3. Experimental condition

The main experimental parameters for performing this gasification experiment were presented in Table 2. The CWS feeding rate was 20 kg/h for each experiment, approximately 13 kg/h LJ coal feeding. The experiments can be divided into two groups, Group A and Group B. Group A represented the experiments without second stage water supply, and Group B represented the experiments with water supply through the second stage nozzles.

The molar ratio of O/C was defined as the ratio between O (including oxygen element of O_2, steam and coal) and fixed carbon of coal, derived as [5,17,20,21]:

$$\lambda = \frac{n_{o,c} + n_{o,o} + n_{o,s}}{n_{c,c}} \tag{1}$$

where $n_{o,c}$ is the mole fraction of oxygen in coal sample, $n_{o,o}$ is the mole fraction of oxygen in first stage and second stage O_2, $n_{o,s}$ is the mole fraction of oxygen in the second stage oxygen element, and $n_{c,c}$ is the mole fraction of fixed carbon in coal sample.