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An experimental study on the drying kinetics of lignite in high temperature nitrogen atmosphere

Hong-Jun Zheng [a], Shou-Yu Zhang [a,*], Xi Guo [a], Jun-Fu Lu [b], Ai-Xia Dong [a], Wen-Xiang Deng [a], Wen-Jiao Tang [a], Meng-Hao Zhao [a], Tao Jin [a]

[a] Department of Thermal Engineering, School of Energy and Power Engineering, University of Shanghai for Science and Technology, Shanghai 200093, PR China
[b] Department of Thermal Engineering, Tsinghua University, Beijing 100084, PR China

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ABSTRACT

The Chinese lignite upgrading process with high temperature nitrogen as a drying agent using a horizontal fixed-bed reactor was addressed and a kinetic model for the single particle lignite drying process was developed based on the experimental results. The results show that the lignite drying process consists of two stages, one is drying rate increasing stage and the other is drying rate decreasing stage. The lignite drying process can be promoted by initial nitrogen temperature increasing and lignite particle size decreasing. The effective diffusivity coefficient (D_e) of the moisture from the lignite particle during the drying process with different initial temperature was obtained theoretically by calculation. The activated energy of the moisture emission from the lignite with different particle size (10–25 mm) was also obtained.

1. Introduction

Lignite is a primary and important energy source which constitutes significant supplies for both energy and chemical feedstock because of its abundance, easy access, and low mining cost. It is estimated that nearly half of the world's coal reserves consist of lignite [1]. In China, lignite is also an abundant fossil reserve and promising energy resource. The lignite resource is mainly located in Inner Mongolia Autonomous Region and Yunnan province, China. About 4.51% of the total raw coal production of China in 2006 was provided from lignite whose production reached about 105 million tons. At present, lignite is mainly used in power stations for the generation of electricity. But its high moisture content (25%–65%), low calorie value and easy spontaneous combustion cause serious problems for its utilization [2–5]. The direct combustion of lignite in boiler can lead to low thermal efficiency, high greenhouse gas emission and high operation and maintenance costs [6,7].

Various dewatering technologies for lignite upgrading with their own respective merits and limitations have been developed throughout the world [8–12]. Among these technologies, the evaporative drying processes using direct or indirect dryers of fixed beds, fluidized beds or rotary kilns with heated air, flue gas or superheated steam as drying agent are in principle suited for lignite upgrading [13–15]. In the conventional low temperature drying processes, the drying efficiency is low and the processed lignite is susceptible to fire and explosion hazards. To avoid the problems, a dewatering technology using high temperature flue gas as a drying agent has been developed and paid more attentions. The high temperature drying technology is widely used in the pulverized coal making system of power plant. In the system, lignite coal is mixed with high temperature flue gas and preliminarily dried in vertical pipe. Then, the mixture is sent into fan coal mill in which the coal is milled and dried further into dry pulverized one. Meanwhile, the downsteam vibrated bed dryer with high temperature flue gas as a drying agent has been applied successfully by Chinese CPI Mengdong Energy Group Co., Ltd. for large scale Baiyinhua lignite upgrading [16]. The flue gas of 500–800 °C can be used as drying agent for the large-scale lignite upgrading [17].

The study on the convective drying mechanism of single lignite particles has important academic and practical significances for the development of lignite dewatering technologies. To simulate the drying process of granular material in superheated steam, a single-particle model for lignite particle drying had been developed by Chen et al. [18]. The model was based on the shrinking core assumption. Because of no availably experimental data on the coal drying process in the literature, the proposed model was not verified. Subsequently, based on the receding core assumption, a mathematical model on the drying process of single particle ceramic in pressurized superheated steam was also developed and tested against experimental results [12,19]. The model can

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* Corresponding author at: Department of Thermal Engineering, School of Energy and Power Engineering, University of Shanghai for Science and Technology, 516 Jungong Road, Shanghai 200093, China. Tel.: +86 18939950839; fax: +86 21 65711123.
E-mail address: zhangsy-guo@163.com (S.-Y. Zhang).

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Table 1
Proximate and ultimate analysis (wt%) of YM.

Proximate analysis					Ultimate analysis (ad)				$S_{t,ad}$
M_{ar}	M_{ad}	A_{ad}	V_{ad}	FC_{ad}	C	H	N	O	
36.7	7.08	13.50	36.18	43.23	56.96	3.61	0.95	17.31	0.59

ad is the air dried basis; M_{ar} is the moisture (air received basis); M_{ad} is the moisture (air received basis); A_{ad} is the ash (air dried basis); V_{ad} is the volatile matter (air dried basis); FC_{ad} is the fixed carbon (air dried basis).

be used to predict the drying rate, the drying time and the moisture content of porous ceramic particles. In the past several years, many Chinese researchers have researched the low temperature drying process of some typical lignite based on the diffusion theory [20–23]. Based on the widely used receding core model and the diffusion model, considering the effect of lignite microstructure, an improved receding core diffusion model was developed.

In the work, the effects of the initial nitrogen temperature and particle size were investigated. Then, the drying kinetics of single lignite particles in the high temperature drying process was mainly researched. Finally, a mathematical model was developed for the lignite particle drying process with heated nitrogen as a drying agent [17].

2. Materials and methods

A Chinese lignite coal used in these experiments was Yimin (YM) lignite of Inner Mongolia. The ultimate and proximate analyses of the raw coal are listed in Table 1. The spherical lignite particles of four sizes (10, 15, 20 and 25 mm) were chosen for the following experiments and numerical simulation. The moisture contents of the samples were analyzed on as received basis. To determine the original moisture content of the samples, the lignite particles of four sizes (10, 15, 20 and 25 mm) were dried at 105 °C for more than 2 h in an electric drying oven. Meanwhile, the raw materials were placed in the sealed container which was put in a shady environment to serve for the following experiments.

The drying experiments were carried out in a horizontal fixed-bed dryer shown in Fig. 1. Nitrogen with flow rate of 60 L/h was first purged into the preheater whose temperature was set at 600, 700, 800, and 900 °C according to the experimental design. Then the preheated nitrogen flowed into the dryer, which ensured that there was no oxygen in the out-let gas. The experiment steps were designed as follows: The spherical lignite particle with two thermocouples was firstly placed in a basket fixed with the front-end of the push rod. One thermocouple was placed closely on the surface of the lignite particle to monitor the change in the surface temperature of the sample. The other one was used to measure the surrounding temperature of the lignite particle. When the temperature of the dryer reached the designed level, the push rod was pushed into the center of the dryer quickly and timing begins simultaneously. After the designed residence time of the lignite particle, the push rod was pulled out and the treated lignite was kept in a cool nitrogen atmosphere at the end which is cooled indirectly by water until the particle was cooled down to room temperature. So the treated sample can be cooled immediately and further drying can be avoided. Moreover, the oxidation and combustion of the treated samples can be prevented. Finally, the lignite particle was weighed to determine the weight loss of the sample during the drying process.

The moisture content on dry basis is the weight of moisture contained in per unit weight of the dry matter in the product [24]. The moisture content can be calculated through the following equation:

$$X_t = \frac{m_t - m_\infty}{m_\infty} \qquad (1)$$

where X_t is the instantaneous moisture content of the sample, m_t is the weight of the sample at time t and m_∞ is the dry sample weight.

DMR represents the dimensionless moisture ratio and can be obtained by the following equation:

$$\mathrm{DMR} = \frac{X_t - X_e}{X_0 - X_e} \qquad (2)$$

where X_0 is the original moisture content of the sample and X_e is the equilibrium moisture content. The equilibrium moisture content is the maximum inherent moisture content under a certain temperature and humidity.

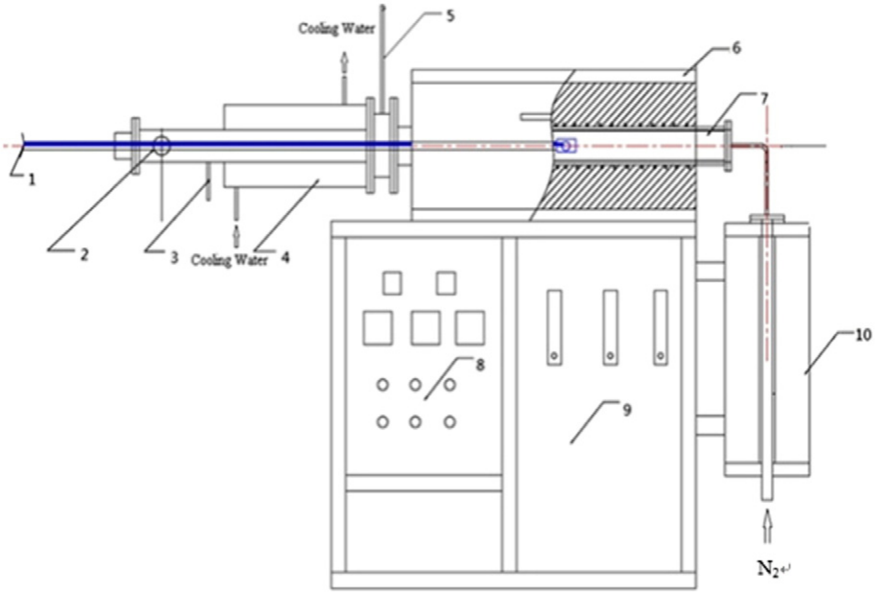

Fig. 1. Horizontal fixed bed drying installation. 1—push rod with coal loading basket, thermocouples and nitrogen inlet; 2—operating hole; 3—cooling nitrogen inlet; 4—water-cooling jacket; 5—nitrogen outlet; 6—electric heater; 7—dryer; 8—controller; 9—panel with flowmeters; 10—preheater.