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Research article

The influences of moisture on particle ignition behavior of Chinese and Indonesian lignite coals in hot air flow

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A B S T R A C T

The effect of moisture content on ignition and combustion behavior of Chinese (HL) and Indonesian (YN) lignite were investigated. Particles with a size range of 75–105 μm with different moisture contents were injected in a bench-scale, electrically heated transparent reactor and the combustion of individual particles was observed with a high-resolution high-speed camera. Direct ignition observations indicated that most of the HL lignite particles underwent extensive fragmentation during ignition. Fragmentation was attributed to the explosive diffusion of volatiles and water vapor to the particle surface as a result of fast heating rate. Fragmentation reduced the particle size and increased the possibility of heterogeneous ignition of individual fragments. YN lignite particles on the other hand, underwent one-mode whole particle ignition upon heating. Higher moisture content caused a significant ignition delay in both lignite samples. 10% and 20% moisture in lignite samples resulted in around 83 and 160 ms delay in ignition for both coals. Higher intensity of fragmentation of HL particles during combustion compared to YN lignite resulted in shorter total particle combustion time at higher moisture contents. The findings of this study advanced the knowledge of the effects of moisture on ignition and combustion of low-rank coals.

1. Introduction

Coal is one of the main energy sources to meet the global energy demand in the future due to more abundant reserves compared to other fossil fuels [1]. Approximately 40% of the global electricity is generated by burning coal [2]. With increasing the energy demand and price of high-rank coals, lower rank coals are being increasingly utilized. Low-rank coals such as lignite have advantages of low mining cost, high volatile matter content and low amount of pollution forming elements [3]. However, low-rank coals contain high amount of moisture (25–60%) that significantly limits their application including combustion and gasification [4]. The high moisture content in lignite may cause unfavorable limitations in thermal efficiency of power plant and lower energy output compared to higher rank coals [5]. Obtaining optimal operating conditions have been proven difficult when low-rank coals are used in a pulverized coal boiler [6]. Therefore, low-rank coals are generally dried by using the warm exhaust gas before combustion [7]. The conventional thermal drying processes cannot guarantee the complete removal of water in coals. On the other hand, thermal drying is an energy consuming process and decreases the efficiency of the power plant. Therefore, it is important to investigate the effect of moisture content in low-rank coals on their ignition and combustion behavior.

Combustion of solid fuel particles may occur in homogeneous or heterogeneous mode. The homogeneous combustion is primarily caused by devolatilization and subsequent ignition of the volatile matter, which usually takes place under slow heating rates (<100 Ks^{-1}), and relatively large particle size (>100 μm). On the contrary, the heterogeneous combustion occurs by the direct attack of oxygen on the whole coal particles under the rapid heating rate conditions (>100 Ks^{-1}) in smaller particles (<100 μm) [8]. The evolution of volatile matter and homogeneous combustion, and the heterogeneous combustion of the char may occur separately or simultaneously depending on several factors such as coal rank [9–11], particle size [6], heating rate [8], coal feeding rate [12], the stoichiometry [2], gas composition [13], and temperature [12]. Devolatilization in the early stages of the combustion results in formation of tar, hydrogen, and light hydrocarbons around the surface of the particle [14]. The effect of volatiles evolution varies in different coal types [15]. The diffusion of volatiles to the particle surface causes swelling in bituminous coals [16,17] and in some cases fragmentation in low-rank coals [17,18]. Khatami and co-workers reported a mixed heterogeneous/homogeneous behavior during lignite ignition [10,19]. This was attributed to fragmentation tendency of lignite particles during combustion. The timing of fragmentation has also

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Table 1
Proximate and ultimate analyses of lignite samples used in this study.

Sample	Hailar lignite (HL)	Indonesian lignite (YN)
Moisture (wt%, ar)	30.87	20.38
Volatile matter (wt%, db)	38.28	37.07
Fixed carbon (wt%, db)	46.82	60.76
Ash (wt%, db)	14.90	2.17
C (wt%, daf)	70.63	71.51
H (wt%, daf)	4.38	4.97
N (wt%, daf)	1.29	1.03
S (wt%, daf)	0.14	0.24
O[a] (wt%, daf)	23.56	22.25

ar: as received; db: dry basis; daf: dry ash free.
[a] Calculated by difference.

been reported to play an important role in the combustion mode of lignite. When fragmentation occurs before ignition, the fragments of the lignite particles tend to ignite heterogeneously [2]. However, when the fragmentation occurs during or after ignition, mixed homogeneous/heterogeneous ignition is more likely to occur [10].

The ignition delay is defined as the time difference between the particle injection and the moment when visible ignition in cinematographic images are observed [2]. Ignition delays of 30 ± 7 ms, 10 ± 2 ms, and 15 ± 4 ms have been reported for anthracite, bituminous, and lignite coal particles, respectively [10,19]. The ignition delay depends on a number of parameters such as heat capacity of the background gas (N_2 or CO_2), the reactivity of the local fuel-oxidizer mixture (oxygen mole fractions), and particle size [13,20,21].

Although the effect of several parameters such as coal rank, combustion environment, particle size, and heating rate on the ignition of lignite has been studied in the literature, little has been reported on the effects of moisture on lignite ignition and combustion behavior. To improve the existing knowledge on coal ignition and understand the effect of moisture content on ignition behavior of lignite, experiments were designed in this study to investigate the effects of moisture in lignite on ignition characteristics and assess the ignition delay and burnout time of individual lignite particles in the hot gas flows.

2. Materials and methods

2.1. Sample preparation

Two lignite coals, Indonesian lignite (YN) and Chinese Hailar lignite (HL) were used in this study. The coal samples were crushed and sieved into a particle size range of 74–105 μm. The proximate and ultimate analyses of the lignite samples are shown in Table 1. It can be seen that YN lignite had a higher fixed carbon and lower ash content compared with HL lignite. Lignite samples with around 20, 10 and 0% moisture content were prepared by adjusting the residence time in drying oven at 105 °C. The moisture content of samples was measured at least twice and the average values are reported here. The standard deviation of the moisture content measurements ranged between ±4% of the average value. The samples with different moisture content were prepared immediately before the ignition tests.

2.2. Coal combustion and ignition experiments

The schematic diagram of experimental setup used for lignite ignition tests is shown in Fig. 1. The experimental setup consisted of a quartz reactor with a sample feeding port at the top of the injector, an electric furnace with a temperature controller, a high speed digital camera connected to a computer, gas supply and an exhaust pump. During ignition tests, coal particles and air entered the laminar flow vertical quartz reactor in one point along the centerline of the reactor. The ignition tests were carried out in air combustion environment with a gas flow rate of 1 l/min, corresponding to a gas velocity of 4.3 cm/s in the quartz reactor. The quartz reactor (70 mm in diameter and 250 mm in length) was placed in an electric furnace which was heated to the desired temperature. The axial gas temperature profile in the quartz reactor under the active gas flow condition was measured continuously by using K-type thermocouples located at different positions along the combustion zone. The gas temperature profile inside the quartz reactor is shown in Fig. 2. The temperature values shown in Fig. 2 are the average of three measurements and the standard deviation ranged between the ±8.6 °C of the average value. It can be seen that the gas temperature increased monotonically with increasing the distance from the injector

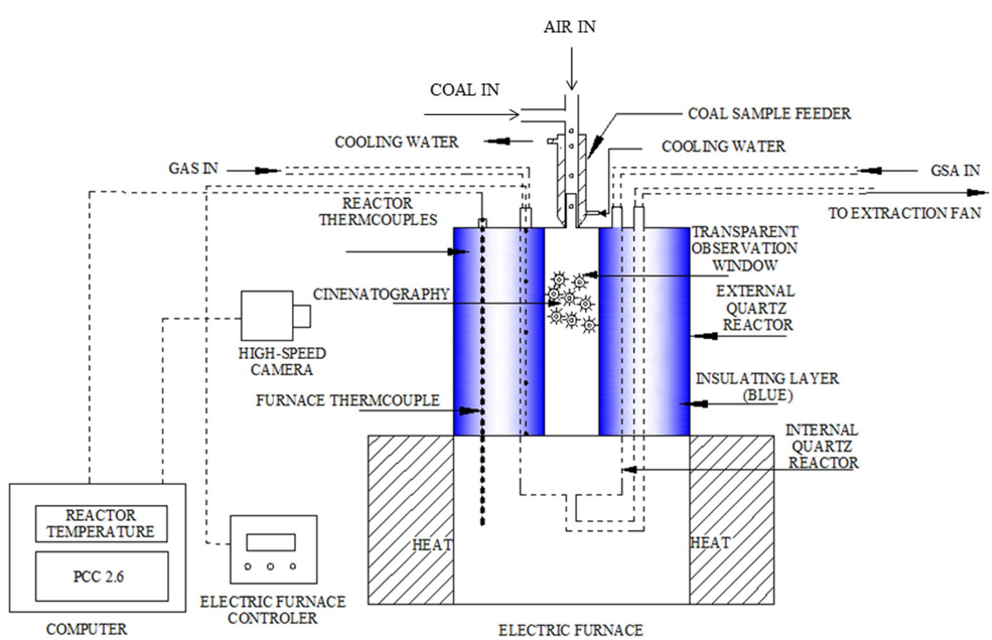

Fig. 1. Schematic diagram of the experimental apparatus.

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