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ScienceDirect
Energy Conversion and Management 48 (2007) 2025–2033
ENERGY CONVERSION & MANAGEMENT
www.elsevier.com/locate/enconman

Volatile release and particle formation characteristics of injected pulverized coal in blast furnaces

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Received 15 June 2006; accepted 8 January 2007
Available online 22 February 2007

Abstract

Volatiles release and particle formation for two kinds of pulverized coals (a high volatile bituminous coal and a low volatile bituminous coal) in a drop tube furnace are investigated to account for the reactions of pulverized coal injected in blast furnaces. Two different sizes of feed particles are considered; one is 100–200 mesh and the other is 200–325 mesh. By evaluating the *R*-factor, the devolatilization extent of the larger feed particles is found to be relatively poor. However, the swelling behavior of individual or two agglomerated particles is pronounced, which is conducive to gasification of the chars in blast furnaces. In contrast, for the smaller feed particles, volatiles liberated from the coal particles can be improved in a significant way as a result of the amplified *R*-factor. This enhancement can facilitate the performance of gas phase combustion. Nevertheless, the residual char particles are characterized by agglomeration, implying that the reaction time of the char particles will be lengthened, thereby increasing the possibility of furnace instability. Double peak distributions in char particle size are observed in some cases. This possibly results from the interaction of the plastic state and the blowing effect at the particle surface. Considering the generation of tiny aerosols composed of soot particles and tar droplets, the results indicate that their production is highly sensitive to the volatile matter and elemental oxygen contained in the coal. Comparing the reactivity of the soot to that of the unburned char, the former is always lower than the latter. Consequently, the lower is the soot formation, the better is the blast furnace stability.

Keywords: Blast furnace; Pulverized coal; Drop tube furnace; Particle size; Soot

1. Introduction

In pulverized coal injection (PCI) operation, the cheaper pulverized coal (PC) is injected with hot air (1100–1200 °C) into blast furnaces (BFs) as a substitute for coke. The economic benefits of the PCI include a reduction in the cost of hot metal, resulting primarily from decreased coke consumption, and an increase in hot metal production. In addition, the coal is consumed directly without going through the coke making plant; the PCI is also thought to be environmentally friendly because it helps to reduce CO_2 emissions [1]. When coal particles are injected and proceeding from the blowpipe, tuyere and then to the raceway, as shown in Fig. 1, they will experience rapid heating (the heating rate is around 10^5 K/s), devolatilization, gas phase combustion, char combustion and gasification [2,3]. These processes obviously include homogeneous and heterogeneous reactions. Regarding the particles dynamics of the pulverized coal, while the coal particles are liberating volatiles, they may undergo swelling [4], fragmentation [5], agglomeration [6] and, eventually, evolve into unburned char particles, which can be consumed by CO_2 in the furnace afterwards. Because the typical residence time for coal particles reaching the bird's nest is around 20 ms [7], the reactions between the gas phase and the solid phase are mainly governed by devolatilization and

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0196-8904/$ - see front matter
doi:10.1016/j.enconman.2007.01.001

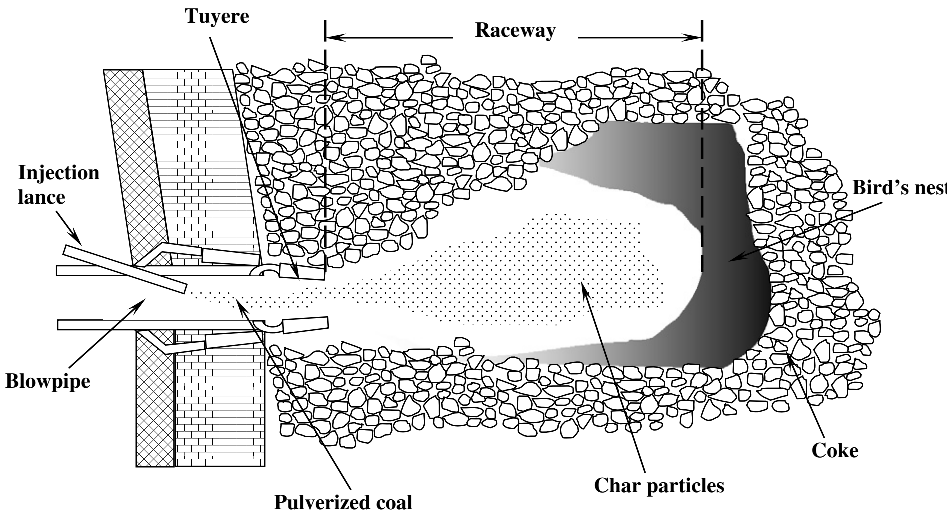

Fig. 1. Schematic diagram of pulverized coal injection and internal structure of blast furnace around raceway.

pyrolysis followed by gas phase combustion. In contrast, unburned char combustion and gasification due to the interactions among carbon, oxygen and carbon dioxide are relatively unimportant in that the characteristic times of the heterogeneous combustion and gasification are, by far, longer than the other reactions mentioned above [3].

In the past, in order to increase the pulverized coal injection rate (PCR), a variety of theoretical and experimental methods have been performed. For example, Ohno et al. [8] investigated PC combustion in a raceway cavity by deriving theoretical formulas; they also experimentally developed a coke packed furnace to evaluate the effect of mixing between the PC and oxygen on the combustion rate. Babich et al. [9] analyzed the effect of coal grinding on PC burning. Though an increase in coal grinding level can raise coal combustion intensity, it also increases the energy waste of the coal grinding. Hence, an optimum coal grinding for PCI into BFs was suggested. The configuration of the injection lance was also studied to achieve higher combustion efficiency. Chung and Hur [10] experimentally conducted a coaxial lance with enriched oxygen going through the annulus to improve coal combustion. They found that the foregoing design is capable of increasing the raceway depth and reducing the bird's nest thickness in consequence of the enhancement of the coal reactions. Ariyama et al. [11] experimentally studied pulverized coal combustion in the tuyere zone by means of single lance and double lance injections. It was illustrated that the performance of coal combustion through the double lance injection is better than that by the other one. This is a result of superior particle dispersion. Similarly, recent numerical predictions of Du and Chen [12] suggest that double lance injection in a blast furnace can facilitate the ignition of coal particles compared to that of single lance injection. They also reported that the PCR in a practical BF has been promoted since the double lance injection was utilized, revealing that the double lance injection does possess the merit of increasing the practice of the PCI.

To pursue cost reduction, a high PCR is always the operation target of a BF; however, once the injection rate is promoted to a certain extent, it will seriously affect the furnace stability. According to the PC trajectories calculated by Du et al. [13], the dispersion of the coal plume to the hot blast in the raceway is poor, resulting in low oxygen concentration within the coal plume. High PCR practice will not only produce more unburned char but also trigger secondary reactions and, thereby, generate a bit of soot [14]. The operation might get worse when the accumulation rate of the unburned char and soot is faster than their consumption, mainly by CO_2 inside the BF. This results in destroying the permeability of the furnace, and generating excessive coke erosion as well as an undesirable temperature distribution and cohesive zone shape [15]. Accordingly, it is recognized that the formation of unburned char and soot within the coal plume and their reactivity in the BF have a vital effect on the stability of the furnace operation. For these reasons, the main interests of the present study are on the characteristics of the volatiles release from PC as well as the related features of unburned char and soot such as char particle size distribution, surface and internal structures of char and reactivity of char and soot. To provide a useful insight into the practice of PCI in BFs, a drop tube furnace (DTF) is developed to simulate coal particle reactions in a coal plume region under high temperature and inert environments. The reactivity of the unburned char and soot will also be evaluated through thermogravimetric analysis (TGA). The obtained results enable us to provide a reference for choosing coals in the performance of BFs.

2. Experiment

Two different coals, denoted by coal F and coal L, respectively, serve as the basis of the present study. These coals are used in the form of PCI for the purpose of getting hot metal in BFs, and their basic properties such as