Energy 34 (2009) 1458–1466

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

An evaluation on rice husks and pulverized coal blends using a drop tube furnace and a thermogravimetric analyzer for application to a blast furnace

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ARTICLE INFO

Article history:
Received 28 November 2008
Received in revised form
5 June 2009
Accepted 10 June 2009
Available online 17 July 2009

Keywords:
Biomass and rice husk
Pulverized coal injection (PCI)
Blast furnace
Drop tube furnace (DTF)
Thermogravimetric analysis (TGA)
Synergistic effect

ABSTRACT

To evaluate the potential of pulverized coals partially replaced by rice husks used in blast furnaces, thermal behavior of blends of rice husks and an anthracite coal before and after passing through a drop tube furnace (DTF) was investigated by using a thermogravimetry (TG). For the blends of the raw materials in the TG, fuel reaction with increasing temperature could be partitioned into three stages. When the rice husks were contained in the fuel, a double-peak distribution in the first stage was observed, as a consequence of thermal decompositions of hemicellulose, cellulose and lignin. A linear relationship between the char yield and the biomass blending ratio (BBR) developed, reflecting that synergistic effects in the pyrolytic processes were absent. This further reveals that the coal and the rice husks can be blended and consumed in blast furnaces in accordance with the requirement of volatile matter contained in the fuel. After the fuels underwent rapid heating (i.e. the DTF), a linear relationship from the thermogravimetric analyses of the unburned chars was not found. Therefore, the synergistic effects were observed and they could be described by second order polynomials. When the BBR was less than 50%, varying the ratio had a slight effect on the thermal behavior of the unburned chars. In addition, the thermal reactions of the feeding fuels and of the formed unburned chars behaved like a fingerprint.

1. Introduction

Pulverized coal injection (PCI) is an important technique in the performance of blast furnaces and it has been widely applied in ironmaking processes for reducing the cost of hot metal production [1]. This arises from the fact that the price of coal is lower than that of metallurgical coke. For this reason, one of the essential targets for producing hot metal from blast furnaces is to promote the pulverized coal injection rate [2,3]. As a matter of fact, PCI coal is consumed directly without going through the cokemaking plant. Hence PCI enables us to reduce CO_2 emissions and prolong the coke oven life [4]. In other words, PCI is considered to be environmentally friendly compared to the ironmaking process only using coke. Though PCI possesses the aforementioned merits, coal pertains to fossil fuels after all and it is not a renewable energy, therefore CO_2 emissions are still inevitable.

Currently, on account of a remarkable fluctuation in oil price and an increase in global temperature, people are deeply aware of the importance of the reduction of CO_2 emissions and the development of alternative fuels [5–7]. Reviewing recently developed renewable energy technologies, biomass has received a great deal of attention as a sustainable fuel source. It is known that plants absorb CO_2 when they grow. If the biomass is burned for the purpose of getting heat, power and electricity, the same amount of CO_2 will be emitted into the atmosphere. Accordingly, biomass is considered as a renewable and carbon-neutral fuel [8,9]. By virtue of the chemical energy contained in the biomass, it is especially applicable to the processes concerning heat treatment such as gasification and combustion used in power plants [10].

In the past, in order to understand the possible applications of biomass blended with coals in industries, a number of studies concerning co-firing [9,11,12], co-gasification [13–15] and co-pyrolysis [16–19] of blended fuels of coal and biomass have been carried out. For example, in the study of Biagnini et al. [11] concerning the phenomena of co-firing, it was reported that the coal didn't have a significant effect on the primary reactions of thermal decomposition of biomass fuels. Similarly, the coal did not seem to be influenced by the release of volatile matter from biomass. Regarding NO_x emissions, Liu et al. [12] stated that lower NO_x emissions might be found during co-combustion. This arises from that fact that fuel-N that existed in biomass was predominantly liberated as NH_3, which could lead to the formation of NO_x and but also acted as a reducing agent in further reactions with NO_x to form N_2.

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0360-5442/$ – see front matter
doi:10.1016/j.energy.2009.06.033

When co-pyrolysis of coal and biomass was considered, Pan et al. [16] carried out a number of experiments of TGA to realize the pyrolytic behavior of pine chips, black coal, waste coal and several biomass-coal blends. It was pointed out that the thermal behavior of the waste coal was poor compared with pine chips and even black coal. When a minimum of 40% of pine chips was blended with 60% of waste coal and reacted under the same conditions, the rate of weight loss increased sharply and was similar to that of black coal. However, no interaction took place between biomass and coal in a blend during pyrolysis. Kastanaki et al. [17] used a TG to study co-pyrolysis of coal and four biomass materials. As a result, no substantial interactions were also observed in the solid phase when the coal and the biomass materials were blended. As a consequence, kinetic modeling of the blends could be successfully performed using the kinetic parameters obtained for the separate blend's components.

The aforementioned studies related to the reactions of blending coal and biomass fuels have provided much information to aid in facilitating the understanding, manipulation and performance of boilers using biomass. In contrast, relatively little research has been performed on blast furnaces using biomass as a fuel. It is known that rice is a very important food and a large amount of rice is grown in many countries. For example, in Taiwan, 783,413 tons of rice were produced in 2007. This implies that the disposal or treatment of the derived rice husks is a notable environmental issue. If the rice husks are utilized in blast furnaces as an alternative fuel, both the imported fuels and CO_2 emissions can be reduced to a certain extent. For this reason, the present study is intended to explore the thermal decomposition of a pulverized coal mixed with rice husks at various blending ratios. A drop tube furnace will be employed to produce unburned chars after the blending fuels experiencing rapid heating. The obtained results can provide a useful insight into the application of rice husks in blast furnaces.

2. Experimental

Fig. 1 shows the schematic of pulverized coal injection and internal structure of a blast furnace around the raceway. When coal particles are injected into the blast furnace, they will undergo rapid heating, devolatilization, gas-phase combustion as well as char combustion and gasification [20]. The characteristic times of heating, devolatilization and gas-phase combustion are very short so that they are mainly achieved in the raceway. In contrast, the char combustion and gasification pertain to heterogeneous reactions, rendering that their characteristic times are long compared to the reactions mentioned above [21]. Accordingly, the char combustion and gasification mainly develop near the bird's nest. In the present study, the synergistic effects of the blended fuels of coal and biomass will be investigated through the TGA to understand the potential of rice husks used in blast furnaces. Similarly, the synergistic effects of unburned char stemming from the fuel's reactions in a DTF will also be examined through the TGA to realize their phenomena occurring in the bird's nest.

2.1. Properties and preparation of samples

It is known that the volatile matter and moisture of biomass is generally higher than that of coal [22]; hence, the heating value of biomass is relatively low compared with that of coal. In order to provide a comprehensive study on the blends of coal and biomass, an anthracite coal with very low volatile matter was chosen. With regard to the biomass, rice husks were selected as the fuel to be blended with the coal, as described before. The properties of the coal and the rice husks, such as proximate and ultimate analyses as well as higher heating value, are given in Table 1. As shown in the table, the volatile matter and higher heating value of the coal are 6.32% and 27,773 kJ/kg, respectively, whereas they are 78.93% and 15,841 kJ/kg in the rice husks. It is also noted that rice husks have significantly less fixed carbon and more nitrogen compared to that of the coal. To simulate the situation of fuels used in the raceway of the blast furnace, the coal and the rice husks were individually grounded. The particle sizes of the fuels were controlled between 100 and 200 mesh (74-149 μm) in that these particle sizes were frequently employed in PCI. The samples were then mixed in accordance with designed biomass blending ratios (BBRs). In the present study, five BBRs of 0%, 25%, 50%, 75% and 100% were taken into account.

2.2. Thermogravimetric analysis (TGA)

When investigating the characteristics of coal reaction, the devices of thermogravimetry (TG) [19,23] and drop tube furnace (DTF) [24,25] are commonly employed. Corresponding to the TG and DTF the heating rates are approximately in the orders of $10\ K\ min^{-1}$ [4] and 10^4-$10^5\ K\ sec^{-1}$ [23], respectively. Considering the thermal behavior of the coal, rice husks and unburned char, they were analyzed by means of a TG (PerkinElmer Diamond TG/DTA). The functions of the TG are to measure and record the

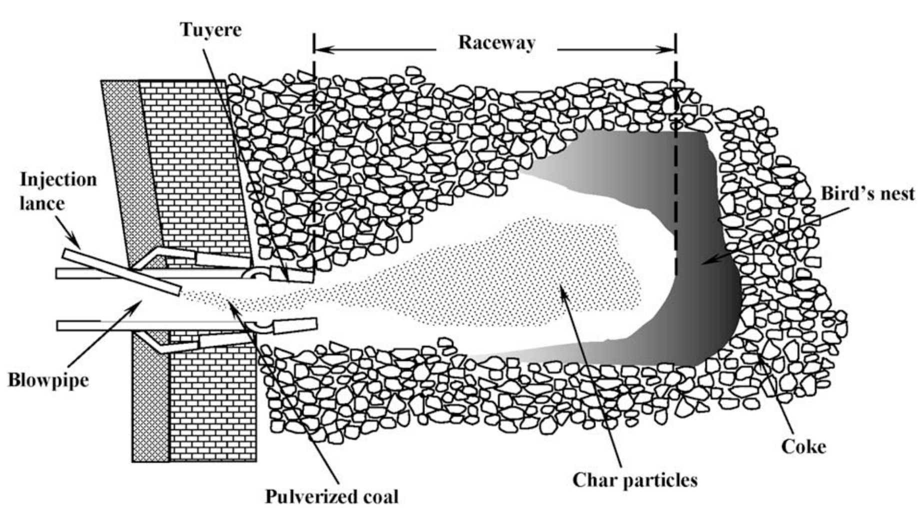

Fig. 1. Schematic of pulverized coal injection and internal structure of a blast furnace around raceway.