Fuel 104 (2013) 194–200

Contents lists available at SciVerse ScienceDirect

Fuel

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

Characteristics and synergistic effects of co-firing of coal and carbonaceous wastes

Tao Wu [a,*], Mei Gong [b], Edward Lester [b], Philip Hall [a]

[a] Division of Engineering, The University of Nottingham Ningbo China, Ningbo 315100, China
[b] Department of Chemical and Environmental Engineering, The University of Nottingham, Nottingham NG7 2RD, UK

HIGHLIGHTS

- ▶ Combustion characteristics of coal and carbonaceous wastes blends were studied.
- ▶ An improvement on ignition at more carbonaceous wastes in blend was observed.
- ▶ Combustion performance of coal and carbonaceous wastes blends is improved.
- ▶ Significant changes in combustion behaviours suggest notable synergistic effects.

ARTICLE INFO

Article history:
Received 17 June 2011
Received in revised form 31 July 2012
Accepted 31 July 2012
Available online 23 August 2012

Keywords:
Co-firing
Synergistic effect
Combustion characteristics
Ignition

ABSTRACT

Co-firing has become a general practice in conventional pf power plants in western countries nowadays. Knowledge on ignition behaviours, combustion characteristic and possible synergistic effects when coal is co-fired with carbonaceous wastes is of importance to operators in terms of selecting the right coal substitutes for co-firing to prevent problems such as mill fires, to maintain good flame stability, and to achieve targeted emission levels. In this study, a Spanish coal and a South Africa coal were blended with four types of carbonaceous wastes at three different mass fractions. The change in ignition behaviour after blending together with overall combustion characteristics was studied using thermogravimetric analysis. Results showed lowered ignition temperatures at higher blending fraction levels. The decreases in both peak temperatures and burnout temperatures are significant regardless of the type and the amount of carbonaceous wastes being blended in the fuel mixture. These lowered characteristic temperatures would normally result in improved overall combustion performance in utility boilers. Moreover, significant changes in burning profiles of coal blended with the same carbonaceous wastes in different mass fractions (especially those for Tyre Scraps) suggest notable synergistic effects during co-firing.

1. Introduction

To mitigate CO_2 emissions, biomass and other carbonaceous wastes have been widely used to replace a proportion of coal in co-firing power stations for electricity generation [1]. Although coal is derived from ancient carbonaceous materials, combustion performance of coal, biomass and other carbonaceous materials is very different from each other in many aspects, such as ignition temperature, flame temperature, reactivity and ash fusion temperature. To minimize the possible negative impacts of co-firing on the operation of power stations, it is necessary to understand the interactions between coal and biomass, the change in combustion characteristic and possible synergistic effects of coal–biomass blending in pf boilers that are designed for the firing of coal and coal blends. Ignition is an important step in combustion process, which has direct influence on flame stability and pollutants formation [2,3]. Extensive research on ignition mechanisms has revealed that ignition normally occurs in two modes: homogeneous ignition, in which volatiles released are ignited followed by the ignition of char, and heterogeneous ignition, in which a simultaneous ignition throughout the whole particle occurs [4]. Normally, the mechanism of ignition is not only an inherent property of fuels [4,5]. It is also significantly affected by other factors, such as particle size, heating rate in the furnace, surrounding gas atmosphere and operating conditions.

The ignition behaviour of coal/coal-blends [2,3,6–8] and biomass [9–11] has been studied extensively. Although co-firing has become a general practice in coal-firing power plants in major European countries, the impact of biomass blending on combustion characteristics, such as ignition, synergistic effects and flame stability, has not yet been studied systematically and therefore not fully understood [12–14].

Thermogravimetric techniques (TGA) have been widely adopted as a cost-effective method to assess ignition behaviours of different

* Corresponding author. Tel.: +86 (0) 574 8818 0269; fax: +86 (0) 574 8818 0125.
E-mail address: tao.wu@nottingham.edu.cn (T. Wu).

0016-2361/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.fuel.2012.07.067

fuels by comparing ignition temperatures and other factors under similar operating conditions [2,3,6,15,16] although the extrapolation of the results to larger scale devices is not straightforward [2,6]. Some attempts have been made to understand possible synergistic effects during cofiring in terms of pollutant formation [17–21], ash deposition [19,21,22] and combustion characteristics [20,23–26]. Systematic research is still needed to gain better understanding of ignition behaviour and combustion characteristics of co-firing of coal and carbonaceous wastes.

In the present study, research was carried out to investigate how ignition behaviours and combustion characteristics of blends are affected by blending coal with different carbonaceous wastes in different mass fractions. Possible interactions during co-firing between coal and carbonaceous wastes were also studied by in-depth investigation on combustion characteristics of blends and those of pure coal and carbonaceous wastes samples.

2. Experimental

A South African coal (SAC) and a Spanish coal (SC) together with four carbonaceous wastes, i.e. Bagasse, Residual-Derived Fuel (RDF), Tyre Scraps and Waste-Derived Fuel (WDF), were selected for testing. These two coals are of high ash content and relatively poor combustion performance in utility boilers. It is one of the aims of this study to explore the opportunities to improve combustion performance of these low quality coals via cofiring with carbonaceous wastes.

In this study, carbonaceous wastes samples were blended with coal in three different mass fractions: 10%, 20% and 30% respectively, which are relevant to current blending practice in pf power stations.

Both coal and carbonaceous wastes samples were ground into powder of certain fineness prior to any tests. SAC, SC, Bagasse and WDF are relatively easy to be ground into fine powder. These samples were milled to −125 μm in size using a tumble mill. The grindability of RDF and Tyre Scraps is significantly lower compared with other samples. RDF was co-milled with dry ice to achieve a fineness of −300 μm. Tyre Scraps were chopped using a Retcsh mill into a fineness of −300 μm.

Proximate analysis was performed using a thermogravimetric analyzer (TGA Q500, TA Instruments) following the standard procedures described elsewhere [27]. Ultimate analysis was carried out using FlashEA 1112 CHNS (CE Instruments). The testing method adopted was the standard procedure suggested in the operation manual.

Combustion characteristics of coal, carbonaceous waste samples and their blends were measured using a non-isothermal technique commonly adopted by many others [28]. All samples, including Tyre Scraps and RDF, were further manually ground to a smaller size (normally less than 125 μm) prior to testing to minimize size effects. Around 8 mg of each sample was heated in air to 300 °C at 50 °C/min and then to 900 °C at 10 °C/min. A gas flow rate of 50 ml/min was used. The temperature at which the weight loss (dW/dt) reaches a maximum is known as peak temperature (PT), and the temperature where burnout rate falls below 1% per minute (on a weight basis) is known as burnout temperature (BT). Normally, both PT and BT temperatures can be used as indicators of combustion characteristics of carbonaceous materials [28]. These temperatures were used to assess the change in combustion characteristics after blending [29].

To determine the ignition temperature of one sample, two sets of tests were carried out using similar amount of representative sample but under different atmospheres, with or without the presence of air. Ignition temperature is the temperature at which the two weight–temperature curves deviate from each other [8].

Possible synergistic effects were studied by close investigation on the changes in major combustion characteristics of coal, carbonaceous wastes and their blends in a series of TGA tests.

3. Results and discussion

3.1. Proximate and ultimate analyses data

Proximate analysis data of individual samples are shown in Table 1. Volatile content varies significantly among the samples investigated, which suggests significant different ignition behaviours and other combustion characteristics of individual coals, carbonaceous wastes and their blends. Both SAC and SC coals have relatively high ash content compared with coals normally being fired in power stations. SC coal is a young coal with a high volatile content of 54.6% (daf). Therefore, SC coal is easier to be ignited and burns easily compared with SAC coal. The four carbonaceous waste samples investigated have significantly different volatile contents. RDF has the highest volatile content of 96.6% (daf), whilst Tyre Scraps and Bagasse have a lower volatile content around 80.0% (daf). Generally, carbonaceous wastes have higher volatile content than coal. Due to the higher volatile content in carbonaceous wastes, chars derived from carbonaceous wastes are much more porous than chars derived from normal coals under the same operating conditions. The porous structure in char normally results in a better accessibility of carbon to oxygen and therefore a better burnout rate.

Table 2 lists ultimate analysis data and calorific values of all samples tested in this study. The oxygen contents of all these individual samples lie in three significantly different ranges, Bagasse 43.9 wt% and WDF 46.8 wt%, SAC 15.7 wt% and SC 20.3 wt%, and Tyre scraps 7.8 wt% and RDF 8.4 wt%. Bagasse and WDF are naturally formed carbonaceous materials. Their oxygen contents are normally high. Normally the high level of oxygen content favours cross-linking carbon chain, which will subsequently inhibit carbon ordering in combustion process and therefore contributes to a higher burnout rate at later stages of combustion. Generally, char burnout stage plays major role in determining the overall time required to achieve a high carbon conversion rate. Hence, Bagasse and WDF would normally exhibit higher reactivity than that of both Tyre scraps and RDF which are of lower oxygen contents (7.8 wt% and 8.4 wt% respectively).

These two coal samples have relatively high oxygen contents around 15.7 wt% and 20.3 wt% respectively, comparing with coals normally being fired at power stations. They are relatively young coals and their combustion reactivity is expected to be fast. Compared with Tyre Scraps and RDF which are of relatively lower oxygen content, after devolatilization, these coals would result in chars of less carbon ordering than chars derived from Tyre Scraps and RDF. Therefore, the intrinsic reactivity of chars derived from these two coals should be higher than that of chars derived from Tyre Scraps and RDF. However, the much higher volatile content in both Tyre Scraps and RDF normally result in the formation of a much smaller amount of highly porous chars after devolatilization compared with SAC and SC coals. Since char burnout stage

Table 1
Proximate analysis data of coal and carbonaceous wastes samples.

Sample	Bagasse	RDF	Tyre	WDF	SAC	SC
Moisture (%)	9.1	4.1	0.3	4.3	3.6	5.3
Volatile (%)	67.3	82.5	64.7	54.8	21.8	41.3
Fixed carbon (%)	17.5	3.0	19.5	7.1	51.7	34.4
Ash (%)	6.1	10.5	15.5	33.7	22.9	19.0
Volatile (daf%)	79.4	96.6	76.8	88.4	29.7	54.6
Fixed carbon (daf%)	20.6	3.5	23.2	11.5	70.3	45.4