Fuel Processing Technology 143 (2016) 7–17

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Modeling of unburned carbon in fly ash and importance of size parameters

Mehmet Bilen *, Sait Kizgut

Faculty of Engineering, Zonguldak, Bülent Ecevit University, 67100 Zonguldak, Turkey

ARTICLE INFO

Article history:
Received 7 August 2015
Received in revised form 6 October 2015
Accepted 27 October 2015
Available online 19 November 2015

Keywords:
Unburned carbon
Pulverized coal size
Size parameters of PSD
Fly ash

ABSTRACT

Unburned carbon (UBC) percentage in coal ash can be considered as an economic and environmental constraint since it is not only an important characteristic in terms of combustion efficiency but also it becomes more of an issue of further utilization of ash. In this study, particle size distribution (PSD) effect on UBC in fly ash (FA) was discussed and efficient size parameter of PSD in terms of UBC formation was determined. At the first stage of the study, regarding ash formation, percentage of any set of coal particles which are more likely to form fly ash (FA) was theoretically determined. For this purpose, a formulation including the size parameters was proposed. Secondly, with the help of a 3-day long systematical control of power, the effect of size distribution on UBC was obtained. The size distributions of these samples showed that an increase in D_{32} size parameter causes an increase in the amount of UBC as well. Relationships between the amount of UBC and mean values of size parameters (D_{10}, D_{50}, D_{90}, D_{32}, D_{43}) were all statistically meaningful for both units of power plant concerned but D_{32} size parameter has a better fit among all the size parameters. In summary, D_{32} & UBC have a regression coefficient of 0.90 ($R^2 \sim 0.9$), while other size parameters (D_{10}, D_{50}, D_{90}, D_{43}) & UBC have regression coefficients of 0.2 ($R^2 \sim 0.2$) for both units. Finally, a model including these size parameters was proposed to predict UBC in FA. The model proposed was in good agreement with the measured UBC in FA.

1. Introduction

Decreasing the amount of UBC have been gaining more importance as new technologies about thermal power plants develop. UBC content in FA usually is in the range of 2–12%, but in some cases it can be up to 20% [3] even 23% [17]. UBC is not only the measure of combustion efficiency but also a measure of possible usage of FA in the cement industry. Possible usage of FA in Turkey is crucial as 29% of the total electric energy demand is supplied by thermal power plants [1]. Therefore, Turkey has a significant fly ash potential. As an example, Afsin Elbistan power plant only consumes 18.0×10^6 metric tonnes of coal per year and generates about 3.24×10^6 metric tons of FA itself [21]. Considering the last 5-year average, it can be estimated that almost 20 million tons of ash most of which is FA has been generated in Turkey and this amount is expected to increase in the near future. According to Acar and Atalay's [2] study, worldwide annual production of coal FA is estimated around 500 million tones, in total.

Minerals in the coal transforms into ash while coal in a pulverized coal (PC) combustion undergoes two different conversion steps, i.e. pyrolysis and char oxidation. Char oxidation is the rate limiting step and determines the carbon conversion and the ash formation. Ash with small amount of residual carbon (UBC) is formed after these conversion steps [13]. Porous structure of coal has significant influence on the formation and the characteristics of ash [6,13,22,25]. Char fragmentation and ash formation mechanism proposed by Wu et al., [22] is given in Fig. 1.

Referring to Fig. 1, fragmentation of highly porous char results in fine ash particles while chars with low porosity result in more compact and coarser ash particles. The effect of particle size of PC on ash formation keeps its complexity. The expected and mostly encountered fact is that the larger the particle size of coal the larger the ash size and more likely to form BA, and if the coal size is finer formation of FA is favored. This may not always be the case, since larger particles with higher porosity and higher internal and external surface area may breakdown and formation of FA is favored. This is also supported by Baxter's [5] study which claims the fact that large char particles have much higher tendency to fragmentation than small particles. Since the PSD of FA of many bituminous coals is generally less than 75 μm [3], formation of these fine particulates may be mostly due to breaking down of large coal chars. In order to understand FA formation clearly not only PSD of Pulverized Coal (PC) and FA but also size means, such as Sauter mean, should be considered. Sauter mean was taken into account by Senneca's study [17] in which Sauter mean was only observed for FA samples and a change between 10 and 27 μm was reported.

The amount of UBC is high due to low oxygen and low temperature combustion conditions to meet emission requirements of NO_x [3] most of the time, however the role of non-ideal PSD of PC on UBC should not be underestimated. Many factors affect the combustion efficiency in

* Corresponding author.
E-mail address: mehmetubilen@yandex.com (M. Bilen).

http://dx.doi.org/10.1016/j.fuproc.2015.10.039
0378-3820/

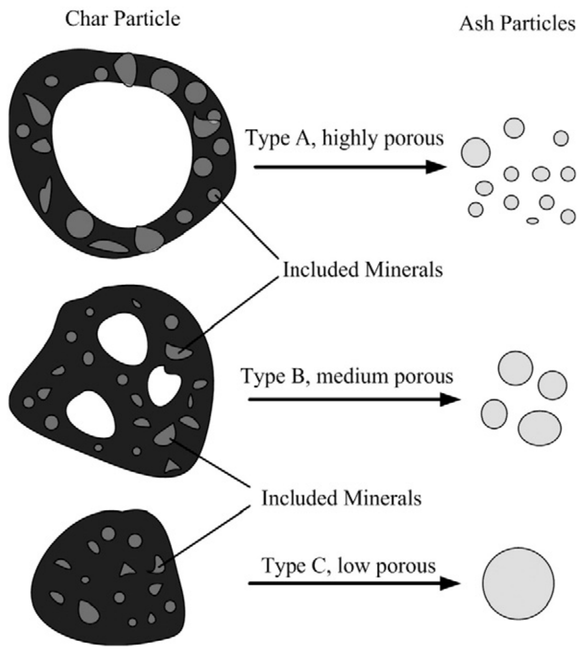

Fig. 1. Char fragmentation and ash formation mechanism proposed by [22].

pulverized fuel boilers. Most effective factors on UBC, i.e. combustion efficiency, are residence time, oxygen feed and the coal properties. Coal properties were studied by Bilen et al. [7] who discussed the effects of moisture content and PSD of coal on UBC in BA. According to Xue et al. [23] coarse fraction of 110–480 μm is important for an efficient PC burnout in coal-fired power plant boilers. Jiménez and Ballester [12] discussed the factors influencing the evolution of particle size during combustion of PC, as well as their consequences for the interpretation of burnout curves. They reported that at early stages of combustion particles (53–63 μm) break into fragments (20–40 μm). Ganguli and Bandopadhyay [10] claimed that there is negligible correlation between PSD of PC and efficiency. Although Ganguli and Bandopadhyay [10] claimed no correlation, it seems that they failed to notice the strong relationship between PSD and efficiency (UBC). Regarding the findings of their study, while PSD 76 of PC decreases from 81% to 46%, UBC in FA decreases from 3.6% to 0.8%. The effect of PSD on UBC was also revealed by Gao et al. [9] that particles larger than 140 μm have contribution of 70% on total UBC although fractional mass ratio of these particles is about 20%. Particle size is also important in terms of heating rate since maximum heating rate decreases linearly with increasing particle size as reported by [24] who claimed that the combustion time increases with increasing particle sizes of biomass from 10 μm to 20 mm. Regarding the combustion time, Atas et al. [4] emphasized the fact that finer coal particles burn more rapidly, and fineness of coal directly reduces the UBC in FA and BA.

Bilen et al. [7] proposed a model to predict UBC in BA which employs D_{90} size and moisture content of feed coal and it was in good agreement with the experimental findings. The achievement of aforesaid correlation simply is a proof to the importance of PSD in terms of UBC either in BA or in FA. In this study, the effect of PSD of PC on UBC in FA was discussed. Size parameters were introduced in FA formation and related formulation was proposed. PSD effect was also investigated with size parameters and amount of UBC in FA was correlated with these size parameters.

2. Materials and experimental procedures

2.1. Combustion units and sample collection

The samples were taken from a local power plant in Zonguldak, Turkey. Schematic representation of these studied samples is given in Fig. 2. Unit 1 and Unit 2, which the samples were provided from have the same type of boilers operated at combustion zone temperature of around 1200 °C. The stockyard coal sample was taken from a huge pile feeding both units. This sample was taken once and proximate analysis was carried out just to have a general idea about the coal characteristics and boiler design requirements. All other samples (PC samples) were taken from the burner points shown in Fig. 2. A total of 801 PC samples, 369 from Unit 1 and 432 from Unit 2, were collected for nine shift periods. The number of PC samples for each shift was 48, PC samples were taken from mill exits twice at each shift. Since there are four exits of each mill and the plant has six mills a total of 48 PC samples were gathered for each shift for each unit. Representation of the combustion environment in terms of size distribution of PC is provided by such a large number of samples.

2.2. Characterization of pulverized coal samples

Sieve analysis of PC samples was done by using Malvern Mastersizer S 2000 utilizing wet method and PSD of PC samples was obtained over a range of 0.05 μm–878.67 μm. Refractive index of water and PC was set to 1.33 and 1.64, respectively. Obscuration of the Mastersizer experiments

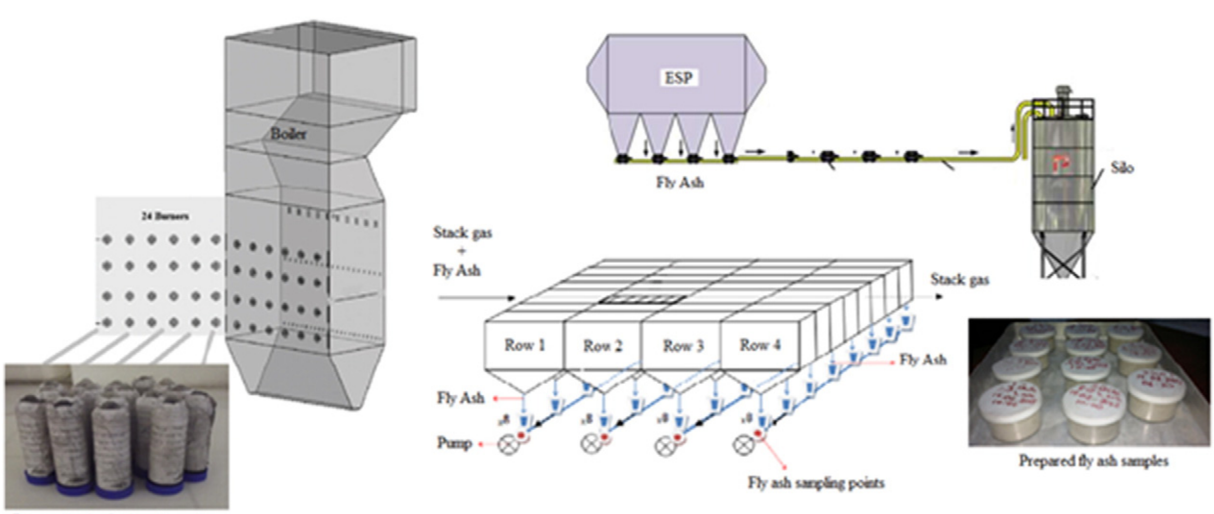

Fig. 2. Schematic representation of sampling. (Representation of boiler is adapted from the study of Li et al. [14]).