Fuel xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Fuel

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

Petrographic controls on combustion behavior of inertinite rich coal and char and fly ash formation

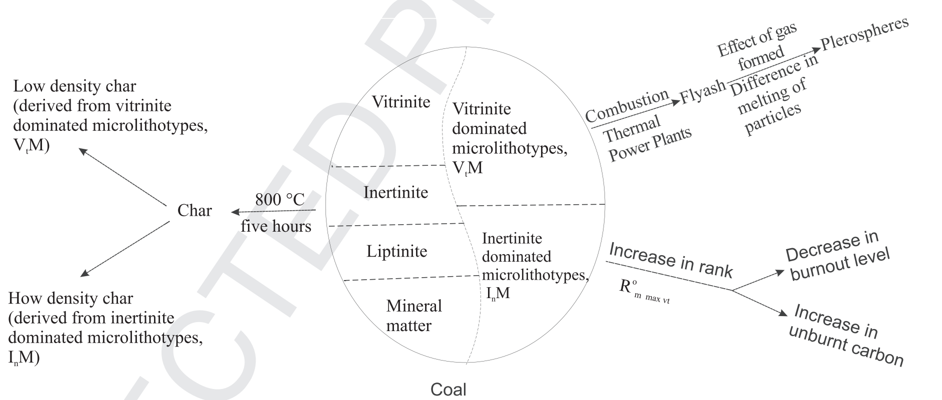
Atul Kumar Varma [a,*], Mrityunjay Kumar [a], Vinod Kumar Saxena [b], Ashish Sarkar [c], Santanu Kumar Banerjee [a]

[a] *Coal Geology and Organic Petrology Lab., Dept. of Applied Geology, Indian School of Mines, Dhanbad 826004, India*
[b] *Dept. of Chemical Engg., Indian School of Mines, Dhanbad 826004, India*
[c] *Dept. of Applied Chemistry, Indian School of Mines, Dhanbad 826004, India*

HIGHLIGHTS

- Burn out level and unburnt carbon amount influenced by rank and inertinite content.
- Organo-petrographic constituents in char is controlled by coal microlithotype.
- The intrinsic reactivity of inertinite is low with respect to other macerals.
- High-density char may be mainly derived from inertinite dominated microlithotypes.
- A new type of char named vitrosphere is reported.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 11 October 2013
Received in revised form 3 March 2014
Accepted 4 March 2014
Available online xxxx

Keywords:
Coal petrography
Coal combustion
Fly ash petrography
Plerosphere
Char petrography

ABSTRACT

The inability to yield heat up to the expected and desired level by a few of the coal fired thermal power plants can primarily be attributed to the ineffectual combustion of coal. In an intensive endeavour to understand the role of petrographic characteristics in combustion behavior, the authors have collected inertinite rich feed coal and fly ash from six different power plants in India. The technological characteristics, petrographic make up (maceral – and microlithotype composition) and vitrinite reflectance of the feed coals were studied in details. The variation in char types were identified in the various fly ashes. The chars from different feed coals were prepared under controlled laboratory conditions. The burn out level and the unburnt carbon amount in fly ash appear to be controlled by rank and inertinite content. The good correlation between the high-density chars and inertinite dominated microlithotype suggests that high-density chars are mainly derived from these related microlithotypes. The presence of a new type of char, named vitrosphere is reported. The fly ash with little unburnt carbon is predominantly comprised of plerospheres.

1. Introduction

Of late, owing to a growing energy demand the importance of coal as a source of energy has grown by leaps and bounds [1,2]. The abundance and vast distribution of coal in different parts of

* Corresponding author. Tel.: +91 326 2235449 (O), 2235549 (R); fax: +91 326 2296563.
E-mail address: atulvarma@hotmail.com (A.K. Varma).

http://dx.doi.org/10.1016/j.fuel.2014.03.004
0016-2361/© 2014 Published by Elsevier Ltd.

the world provides significant guarantee of supply stability to countries with inadequate local resources of fuel [3]. Coal is, however, an extremely complex and heterogeneous material whose physical and chemical properties are not easy to categorize [4–8].

1.1. Previous compilations

The distribution of the various macerals within a particular coal, along with rank changes, to a large extent controls the coal properties and as a consequence, affects the combustion behavior of the coal [9–19]. During the coal combustion process, the potential energy stored is released in the form of heat and power. The coal combustion process can be divided into four stages viz. induction, devolatilization, char combustion and residual combustion. These stages last from a few microseconds to minutes [12,20–22]. Char combustion entails char burning by the diffusion of reacting gas molecules (mainly oxygen) from the furnace to the char surfaces and pore walls where they are temporarily adsorbed and react with active sites [23]. The characteristics of the char that generally influence the progress of burnout, includes (a) the external dimensions of the particles, (b) the volume, size and distribution of pores within the particles, (c) the total internal surface area of the char available for reaction and (d) the intrinsic reactivity [24].

1.2. Physical and chemical properties of ash

Several investigations have been undertaken in an effort to interpret the physical properties of ash [25–27]. Some studies have investigated feed coal, bottom ash as well as fly ash and they have demonstrated a high variability in terms of trace element distribution in the feed coal and related bottom and fly ashes [28,29]. The ignition propensity for various ranks of coal has also been tested [30]. Ash deposition was studied during pulverized coal combustion and oxy-firing [31,32]. The fly ash shows properties that depend upon the coal characteristics, the burning conditions and the collection system. These various properties are used in industrial applications [32–36].

1.3. Anisotropy, porosity and wall thickness of char

Anisotropy of char refers to the size of discernible coke anisotropy domains in the particle walls [37]. The char classification system is based on the physical properties that govern char reactivity and carbonaceous residues of coals produced in both inert and oxidizing atmospheres at temperatures $\geqslant$800 °C. Observations from various power stations support the classification system reasonably well and factually describe the unburnt carbon in the fly ash [38]. Genetic terms for char particles denoting origin from vitrinite or liptinite are seldom used, since after exposure to temperatures of around 800 °C in the furnace, these macerals can no longer be easily recognized [8]. Presently char particle type is defined following Bailey et al. [37]. However, the particle shape of char is related both to the rank and type of feed coal [38]. Elongate and sub parallel orientations of vesicles (taken into account in char classification) may allow greater access to the diffusing gases within the char particle, and it may influence the extent of internal burning [39]. The degree of development of graphitic texture is related to the increase of aromaticity in the char that depends on the liberation or retention of volatiles (during the plastic stage) that are believed to play an important role in char reactivity [40]. The char combustion is the rate-determining step in the overall combustion of the pulverized fuel. It is, therefore, of great consequence to compare char from the various macerals of coal and of different rank to ascertain which char types require longer residence time for burning to completion. An understanding of the coal combustion properties helps in designing and maintenance of boilers, aids in maximizing burning efficiency, and assists in reducing carbon particle emissions.

In this work, the authors have investigated petrographic characters of feed coals from six power plants in India and also attempted to characterize the fly ash of the same power plants. The impact of petrographic composition and rank of coal on char formation have been studied by preparing char in a muffle furnace under controlled combustion conditions.

2. Materials and methods

2.1. Collection of feed coal, fly ash and char samples for various investigations

Six samples of feed coal (FC-A, FC-B, FC-C, FC-D, FC-E and FC-F) and fly ash (FA-G, FA-H, FA-I, FA-J, FA-K and FA-L) were collected from six different Indian power plants viz., A (Damodar Valley Corporation (DVC) Power Plant; Unit-2, Waria, Durgapur, West Bengal), B (Jamadoba TISCO Colliery Power Plant, Jharia, Jharkhand), C (Dishergarh Power Plant, West Bengal), D (Barauni Thermal Power Station, Barauni, Bihar), E (Kahalgaon Super Thermal Power Station, Bhagalpur, Bihar) and F (Bokaro Thermal Power Station, Jharkhand) respectively (Table 1). The feed coal and the fly ash collected from various power plants were subjected to macroscopic, technological and micropetrographic investigations. The technological characteristics including moisture content (W^a), volatile matter yield (V^{daf}), ash yield (A^d) and fixed carbon content (FC^{daf}) were determined (Table 2) by following procedures described in [41]. The micropetrographic study of coal was carried employing a Leitz MPV2 reflected microscope with a fluorescence attachment in both white and ultraviolet light. A Swift Point Counter was used to determine the volume percentages of the various

Table 1
Sample codes for feed coal, fly ash and chars prepared in the laboratory.

Sl. no.	Sample code	Description
1	FC-A	Feed coal-A from power plant No. A
2	FC-B	Feed coal-B from power plant No. B
3	FC-C	Feed coal-C from power plant No. C
4	FC-D	Feed coal-D from power plant No. D
5	FC-E	Feed coal-E from power plant No. E
6	FC-F	Feed coal-F from power plant No. F
7	FA-G	Fly ash –G from power plant No. A
8	FA-H	Fly ash –H from power plant No. B
9	FA-I	Fly ash –I from power plant No. C
10	FA-J	Fly ash –J from power plant No. D
11	FA-K	Fly ash –K from power plant No. E
12	FA-L	Fly ash –L from power plant No. F
13	MC-M	Char prepared in laboratory by pyrolysing FC-A
14	MC-N	Char prepared in laboratory by pyrolysing FC-B
15	MC-O	Char prepared in laboratory by pyrolysing FC-C
16	MC-P	Char prepared in laboratory by pyrolysing FC-D
17	MC-Q	Char prepared in laboratory by pyrolysing FC-E
18	MC-R	Char prepared in laboratory by pyrolysing FC-F
19	MK-1	Unburnt component sample prepared from fly ash, FA-I of power plant No. C for FTIR analysis; unburnt carbon extract solution eluted with petroleum ether
20	MK-2	Unburnt carbon component sample prepared from fly ash, FA-I of power plant No. C for FTIR analysis; unburnt carbon extract solution eluted with benzene
21	MK-3	Unburnt carbon component sample prepared from fly ash, FA-I of power plant No. C for FTIR analysis; unburnt carbon extract solution eluted with dichloro-methane

Explanations: A is the Damodar Valley Corporation (DVC) power plant; Unit-2, Waria, Durgapur, West Bengal; B is the Jamadoba Tisco colliery power plant, Jharia, Jharkhand; C is the Dishergarh power plant West Bengal; D is the Barauni thermal power station, Barauni, Bihar; E is the Kahalgaon super thermal power station, Bhagalpur, Bihar; F is the Bokaro thermal power station, Jharkhand.

Please cite this article in press as: Varma AK et al. Petrographic controls on combustion behavior of inertinite rich coal and char and fly ash formation. Fuel (2014), http://dx.doi.org/10.1016/j.fuel.2014.03.004