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A comprehensive characterisation of fly ash from a thermal power plant in Eastern India

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Abstract

A comprehensive characterisation of fly ash from Bokaro Thermal Power Plant, Jharkhand, India has been carried out for creating utilisation potential of the ash. As received fly ash, was size fractionated and the fractions were characterised. The non-magnetic and magnetic fractions of ash have been analysed in terms of their morphological, mineralogical features and physico-chemical properties. The results of such analysis reveal that there is a striking difference in the features and properties of the coarser and finer particles. The coarser fractions of the non-magnetic component seem to contain high percentage of char and semicoked/coked carbonaceous particles. The percentage of char *albeit* the carbon content decreases with decrease in size of the particles. The particles of the finer fractions have more spheroidal character than the coarser ones. The non-magnetic components essentially contain quartz and mullite as the main mineral phases. The magnetic component differs from the non-magnetic ones in respect of shape, mineralogical composition and carbon content. These are much more spheroidal than the non-magnetic ones. The ferrospheres present in these components bear crystallites with different geometrical patterns clearly indicating a definite degree of variation in the crystallisation process. Such comprehensive characterisation leads to not only a definite direction about the uses of the various fractions of the ash, but also gives useful informations regarding the prevailing combustion process.

Keywords: Fly ash; Morphological; Physico-chemical properties

1. Introduction

The thermal power plants are still the main source of power generation in India. These thermal power plants have been generating about two thirds of the power demands of the country. There are about forty major thermal power plants in India. The coal used in thermal power plants comes from different coal mines of Eastern, Western, Central, Northern, South-Eastern and Mahanadi Coal fields. The coal companies have been carrying out their activities under the aegis of the corporate office of Coal India Ltd. The Bokaro thermal power plant (BTPP) generates about 200 MW of power. The plant receives its supply of coal from the regional subsidiaries of Coal India Ltd. It generates huge quantity of fly ash. Presently, the ash is being utilised for brick-making, land filling, construction purposes, soil amendment etc. However, it has become essential to carry out a comprehensive characterisation of fly ash generated at the plant so that effective end uses can be made. It was also expected that such a comprehensive characterisation will give useful informations regarding the prevalent combustion process.

Fly ash, a coal combustion residue (CCR) is a complex heterogeneous material. Although, in the strictest sense, fly ash is the finest CCR (0.2–90 μm) formed due to the transformation of mineral matter present in coal particles during combustion [1], it has become a misnomer, particularly in respect of fly ash generated at Thermal Power Plants (TPPs) in India. Because of the poor combustion efficiency of the combustors, lack of proper quality control in maintaining the particle size of the pulverised coal feed etc, the fly ash has a wide distribution of char, semi-coke or coked carbon matters of large dimension (90–300 μm). It is irregularly shaped, containing lacy, vesicular, alumino-siliceous matter of complex composition and fine solid/hollow alumino-siliceous spheres.

The chemical composition of fly ash varies depending upon the type of coal used in combustion, combustion conditions

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and removal efficiency of air pollution control device [2,3]. The lignite and sub-bituminous coals on combustion produce Class C fly ash, while anthracite and bituminous coal under similar process generate Class F fly ash. The sum of SiO_2, Al_2O_3 and Fe_2O_3 content in fly ash should be greater than 70% for Class F fly ash, whereas the CaO content should be less than 5% [4]. The Class C fly ash is classified as [4] those fly ashes having less than 50% of SiO_2, Al_2O_3 and Fe_2O_3 combined. The CaO content varies from 20% to 30% for such fly ash. However, the composition of fly ash may vary to some extent depending upon whether the same is of low/high calcium or low /high iron fly ashes [5]. Class C and Class F fly ashes have significant differences in their properties. Consequently, their utilisation schemes are also different [6].

The mineralogical composition of fly ash is largely dependent upon the geological features related to formation and deposition of coal [7,8], the combustion condition, etc. [9]. The most common and predominant phases are quartz, mullite, hematite, magnetite and lime apart from other minor constituents [10,11]. It also depends upon the type of the coal used. Thus, lignite fly ash has predominantly quartz, anorthite, gehlenite, hematite and mullite as major crystalline phases [12–14]. The low calcium fly ashes contain quartz and mullite as the major crystalline phases, whereas the high calcium fly ashes consist of quartzite, C_3A and C_4AS [8]. Indian fly ashes mostly consist of quartz, mullite, magnetite, hematite, faylite and glass [15].

The morphology of fly ash is an important aspect that requires thorough evaluation. Based on examination using light microscopy, fly ash particles can be classified into eleven morphologic classes [16]. Amongst the carbonaceous particles present in fly ash the most important one is 'char' which is formed due to devolatilisation of the coal particles. Subsequent char burning and intrinsic mineral matter transformation leads to the formation of ash particles [1], which may be in the form of irregular particles, solid and hollow spherical particles. Amongst these, the most important and value added particles are cenospheres, plerospheres and ferrospheres [2,15,17–23]. The aim of the present work is to evaluate the fly ash obtained from a local thermal power plant viz. Bokaro Thermal Power Plant. In this study the major stress has been laid on the physico-chemical and morphological characterisation of the fly ash particles with a special emphasis on the dependence of these properties on the size range of the particles. Such an evaluation is most likely to identify the potential use of the size fractionated fly ashes for various purposes.

2. Material and methods

Fly ash samples were collected from the chimney baghouse of BTPP. The sample is a representative one, in the sense that ashes collected over a period of one month at the baghouse was mixed thoroughly following the standard sampling procedure of coning and quartering. Subsequently, the ash sample was sieved (30 min) using sieves No. B.S 150, 250, 300 and 350.

Accordingly, five size classified fractions namely A, B, C, D and E were obtained. Subsequently, each of the fractions was further separated into magnetic and non-magnetic components using magnetic separator. The fractions A_{11}, B_{11}, C_{11}, D_{11} and E_{11} corresponded to non-magnetic components of each fraction while A_{12}, B_{12}, C_{12}, D_{12} and E_{12} corresponded to the magnetic components. Fraction A denotes particles retained by sieve No. B.S 150 (i.e. +104 μm), B is the fraction retained by sieve No. B.S 250 (i.e. −104 to +66 μm). Fraction C and D correspond to (a) fraction retained by sieve No. B.S 300 (i.e. −66 to +53 μm) and (b) fraction retained by sieve No. B.S 350 (i.e. −53 to +45 μm), respectively. Fraction E represents particles which passed through sieve no. 350 (i.e. −45 μm).

As far as characterisation is concerned, the weight percentage distribution, particle density, particle size, LOI (according to ASTM C311-04), chemical composition (XRF), mineralogical analysis (XRD), morphological analysis using SEM-EDX and FTIR spectroscopic analysis have been carried out for all the fractions. SEM-EDX analysis was done using Scanning Electron Microscope Model S-440, LEO Electron Microscopy equipped with an Oxford link-Isis Energy Dispersive X-ray analyser (EDX). Mineralogical compositions were determined on X-ray diffractrometer Model PW-1710 with Cu K_α radiation. The chemical compositions of the different fractions of fly ashes were determined using PW 2404 X-ray spectrometer. FTIR spectra of the samples were recorded on Perkin Elmer Model–System 2000 using KBr pellet method (concentration 3/100 mg of KBr). The particle size was measured using Laser based particle size analyser namely Mastersizer of Malvern Instruments Ltd. The surface areas of the particles were calculated from the relevant data using the requisite formula. The chemical composition of coal was determined indirectly. Low Temperature Ash (LTA) was obtained for the coal sample and subsequently analysed for their mineral matter composition using XRF. Sieve analysis was also carried out for the feed coal.

Magnetic separation was carried out using Davies tube apparatus. For obtaining carbon rich and carbon depleted fractions from fly ash fraction, column floatation was carried out using methyl isobutyl carbinol (MIBC) and distilled water. The carbonaceous matter floated in MIBC layer and was separated while the carbon depleted fraction settled down at the bottom. Phenol adsorption study was done by ASTM D1783-91 method.

3. Results and discussion

The chemical composition of the feed coal (Table 1) reveals that the feed coal has a very high percentage of ash (nearly 42%). The combined SiO_2, Al_2O_3, Fe_2O_3 content is also substantial (~40%). In absence of CCSEM analysis [9] it will be premature to comment on the intrinsic: extrinsic mineral matter ratio which plays a very important part in determining the physico-chemical properties of the fly ash, particularly that of particle size. However, SEM analysis has revealed the presence of large extrinsic mineral matter.

Sieve analysis of the feed coal, reveals that the particle size range varies widely. It is desirable that for Pulverised Fuel Combustors, the particle size of the feed coal should be less than 75 μm for efficient burning. However, in the present case the percentage of larger coal particles is quite high. This results in inefficient combustion. The larger particle size of the feed coal has another implication. After the larger coal particles had undergone devolatilisation and char burning, a substantial portion of mineral matters left, are quite large. It appears that these have not undergone further fragmentation/transformation and melting. Hence, sieve analysis of the feed coal has given a new insight on the ash formation.