Asian Journal of Chemistry; Vol. 23, No. 5 (2011), 2219-2222

ASIAN JOURNAL OF CHEMISTRY

www.asianjournalofchemistry.co.in

Physico-Chemical Characterization of Coal Combustion Residues From Thermal Power Plants in India

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(*Received*: 12 November 2010; *Accepted*: 28 January 2011) AJC-9530

The object of this study is the coal combustion residues (CCRs) formed during coal combustion in two major thermal power stations in Rajasthan, India. This study determines physico-chemical characteristics and the content of trace elements in coal combustion residues collected from these coal fired power plants. The prevalent disposal methods used at these sites. This is crucial for the potential impact on the geoenvironment from its disposal and utilization; as coal ash has been produced in substantial amounts. The trace element concentrations in coal combustion residues are compared with those reported in literature for an indication of potential environmental implications. Both the sites are shifting from wet collection system to dry collection system which allows better utilizations of coal combustion residues but incurs additional costs. Neither of the sites uses ash pond lining in the construction of the ash pounds, hence leaching of heavy metals is possible. Better management and disposal practices coupled with increased utilization of coal combustion residues need to be undertaken to minimize the adverse impact on the geoenvironment.

Key Words: Coal combustion residues, Fly ash, Disposal, Trace elements.

INTRODUCTION

Coal combustion residues (CCRs) commonly called coal ash is an industrial by-product from coal fired thermal power plants. In India annual generation of CCRs is about 110 million tonnes from more than 70 thermal power stations[1]. By the year 2012, this is predicted to increase to 175 million tonnes per annum (Ministry of power, 2007). About 80 % of the total ash is in finely divided from which is carried away with flue gases and is collected by electrostatic precipitator or other suitable technology. This ash is called fly ash, chimney ash or hooper ash. The balance 20 % of the ash gets collected at the bottom of the boiler and is referred as bottom ash. When fly ash and bottom ash are carried to storage pond in the form of water slurry and deposited, it is termed as pond ash.

In India, at present the major portion of CCRs produced goes for disposal in ash ponds and landfills and only a small fraction of it is utilized[2]. The utilization rate in India is about 13 % which is far below the global utilization rate of 25 %[3]. Typically CCRs have been used for soil stabilization[4], as embankment material[5], structural fill[6], for injection grouting[7], as a replacement to cement[8], in coastal land reclamation[9] and in roads and embankments[10]. The different kind of ashes are suitable for different applications such as:

(i) Fly ash for use as pozzolana and admixture in cement, mortar, cellular light weight concrete (these applications have stringent quality parameters).

(ii) Fly ash for lime pozzolana mixture applications, such as bricks, blocks *etc*., (the quality parameters are not as stringent as in above applications).

(iii) Bottom ash/pond ash for sintered applications, geotechnical applications, structural fills, clay-fly ash brick (burnt type) agricultural applications *etc.*

Due to minute particle size and presence of previously sequestered potentially toxic trace elements, CCRs pose disposal challenges and a threat to environment as it is considered hazardous to living organisms[11]. Some trace elements may leach out of the ash ponds and contaminate the soil, surface and groundwater. These trace elements have been known to limit the survival and growth of plants and microbial population[12]. Apart from being a continuing disposal problem, their uses in soil treatment, as conditioner or filler material for low lying waste lands, in refuse dumps reclamation and constructive or geotechnical secondary material[13-15] increases their potential geoenvironmental impact.

Present study investigates physico-chemical characteristics of CCRs to assess its suitability as pozzolanic material. Selected heavy metals (Cr, Mn, Pb, Zn, Cu, Ni, Co) have also been studied as their presence in environmental concern. The trace elements in CCRs need to be determined and assessed for potential effects on the geoenvironment, hence the study has been undertaken.

EXPERIMENTAL

Description of the study area: The study area includes two coal-based thermal power plants in Rajasthan (Table-1). Both the sites are equipped with ESPs (electrostatic precipitators) for fly ash collection. These two plants generate CCRs about 35,000,00 tones annually. The CCRs generated from these power plants are transported by means of hydraulic transportation to ash ponds that are at an appreciable distance from the power plants. In ash ponds, the coarse particles settle down and clarified water is discharged away. In July and August, 2009 fly and bottom ash samples were collected from the selected sites.

TABLE-1
DETAILS OF SAMPLE SITES

Power plant	No. of units	Total installed capacity	Coal source	Coal consumption per day
Site-1	6 × 250 MW	1500 MW (6 units)	Korba coal field Chattisgarh	25,000 MT
Site-2	2 × 110 MW 3 × 210 MW 2 × 195 MW	1240 MW (7 units)	Korba coal field Chattisgarh	24,000 MT

Physico-chemical characteristics: The physical properties and chemical composition were determined following the procedures of Indian standards as per IS codes[16]. The grain size analysis was carried out as per IS: 2720-part-4 conforming to ASTM D 422 by dry sieve analysis and followed by hydrometer analysis method for the fractions passing 75 μ sieve. The specific gravity was determined according to IS: 2727 guidelines by Le-Chartelier method with kerosine oil.

Trace element analysis: The collected samples were analyzed for chromium, lead, zinc, nickel, cobalt, copper and manganese. The method used for trace element analysis was atomic adsorption spectrometry (AAS). Dry sample (0.3 g) was weighed into a Teflon vessel. 5.0 mL of 75 % conc. HNO_3 and 2.0 mL HF were added to the vessel and kept for digestion in an autodigester for 20 min after attaining a temperature of 180 ºC. After digestion, the sample was filtered and transferred to a volumetric flask and the volume was made up to 50 mL. This sample was used for analysis of trace elements by flame atomic adsorption spectroscopy and final concentrations of trace elements were determined.

RESULTS AND DISCUSSION

Physical characteristics and chemical composition: The chemical composition of CCRs is given in Tables 2 and 3 gives the physical characteristics. The reported values are average of ten representative samples tested for each parameter. The results of particle size distribution have been given in Table-4. Various size fractions such as clay-sized (< 0.002 mm), silt sized (0.002-0.075 mm) and sand sized (0.075-4.75 mm) are presented in the Table-4.

Concentrations of Na_2O, MgO and total S as SO_3 are found to be < 0.10 %. However, samples from both the sites are rich in silicious and aluminous material. The properties of pozzolanic materials used for the manufacture of pozzolana cements, concrete and lime-cement based bricks/blocks are governed by stipulated standards which differ from country to country. A comparison of the requirements (Table-5) for these applications in tems of pozzolanic properties shows that CCR samples possess have fairly good such properties.

From the Table-4, it is noted that fly ash and bottom ash are predominantly silt sized material with very little amount of sand sized particles. It has been observed that 90 % of ash particles are between 0-0.05 mm that indicates a favourite trait for pozzolenic reaction[17].

TABLE-4
PARTICLE SIZE DISTRIBUTION OF COAL COMBUSTION RESIDUES (VALUES %)

Sample	Clay-sized	Silt-sized	Sand-sized
FA 1	9.10	79.66	11.24
BA 1	6.25	71.60	22.15
FA 2	5.51	64.89	29.60
BA 2	5.99	63.01	31.00

Trace element composition: Results of trace element analysis are given in Table-6. Concentration of trace elements was highest in site-1 fly ash, except for Mn. In samples from both sites Cr and Zn were the most abundant elements, while

TABLE-2
CHEMICAL COMPOSITION OF COAL COMBUSTION RESIDUES (VALUES %)

Sample	Fe_2O_3	MgO	Al_2O_3	SiO_2	SO_3	CaO	Na_2O
FA 1	9.36	0.92	26.92	59.10	0.32	1.13	0.24
BA 1	9.55	0.95	27.04	60.62	0.35	1.00	0.21
FA 2	8.92	0.93	27.02	58.80	0.34	1.09	0.20
BA 2	9.02	0.96	28.10	59.33	0.37	1.01	0.19

FA 1: ESP. fly ash, site-1; FA 2: ESP fly ash, site-2; BA 1: Bottom ash, site-1; BA 2: Bottom ash, site-2.

TABLE-3
PHYSICAL CHARACTERISTICS OF COAL COMBUSTION RESIDUES

Sample	Colour	Dry density (kg/m^3)	Optimum moisture content (%)	Permeability (m/s)	Specific gravity
FA 1	Light grey	1340	38.8	$(3.6\text{-}3.8) \times 10^{-6}$	1.99
BA 1	Dark grey	1480	39.7	$(3.2\text{-}3.5) \times 10^{-6}$	2.53
FA 2	Light grey	1290	37.2	$(4.1\text{-}4.4) \times 10^{-6}$	1.89
BA 2	Dark grey	1370	39.1	$(39.42) \times 10^{-6}$	2.03

TABLE-5
REQUIREMENT OF FLY ASH FOR APPLICATIONS IN TERMS OF POZZOLANIC PROPERTIES (VALUES %)

Component characteristics	Present study		British standard BS: 3892	American standard ASTM: C618	Indian standard: 3812 (Part-I): 2003		Indian standard: 3812 (Part-II): 2003	
	FA 1	FA 2			SPFA	CPFA	SPFA	CPFA
$SiO_2 + Al_2O_3 + Fe_2O_3$	95.38	94.74	–	70	70	50	70	50
SiO_2 Min	59.10	58.80	–	–	35	25	35	25
CaO Max	1.13	1.09	–	–	–	–	–	–
MgO Max	0.92	0.93	4	–	5	5	5	5
Total as SO_3 Max	0.32	0.34	2.5	5	3	5	5	5
Alkali as Na_2O Max	0.24	0.20	–	1.5	1.5	1.5	1.5	1.5

Part-I: For use as pozzolana in cement, cement mortar and concrete. Part-II: For use as admixture in cement, cement mortar and concrete. SPFA: Silicious pulversed fuel ash. CPFA: Calcareous pulverised fuel ash.

TABLE-6
CONCENTRATION OF TRACE ELEMENTS IN COAL COMBUSTION RESIDUES (VALUES mg/kg)

Sample	Cr	Mn	Pb	Zn	Cu	Ni	Co
FA 1	102	63	52	123	82	60	17
BA 1	72	180	15	45	50	32	11
FA 2	83	140	33	62	59	28	8
BA 2	52	85	11	29	40	22	9

Co was the least abundant element. Considerable variation was found in trace element concentration between two power plants samples. It has been reported that the composition of trace elements in coal ash even from a single coal-fired power plant may vary measurably on a daily basis[18].

The results from this study are compared with the ranges of trace elements reported in literature for fly ash in India and from other countries (Table-7). It can be seen that the values are within the range reported for Indian fly ash. It can be observed that some of the trace elements in Indian fly ash as reported in literature and analyzed in this study are found in lower concentration than in other countries.

Ash handling methods: Both the sites follow wet disposal technique. A small portion of fly ash is collected in dry form. The stacks at the power plants are installed with ESPs for the collection of fly ash of different particle size from the out going flue gas. A major portion of the fly ash is collected as wet slurry. This slurry is transported and disposed in an ash pond. The discharge water from the pond is collected and discharged in a drain. The surface of the pond ash it sprinkled with water. This has the advantage of controlling the fugitive emission by forming a thin film on the surface.

The power plants have the facility to directly fill the fly ash into trucks, which can then be sent to the user. As per the guidelines on utilization of fly ash, pond ash and bottom ash, these are supplied free of cost to all types of user on "as is where is" basis. The fly ash is used for brick and cement manufacturing industries and for filling and embankment of roads and low-lying areas.

Potential for contamination from trace elements: Leaching is the most likely path by which coal ash constituents would become mobile, environmental contaminants[19]. The quantity of elements available for leaching in an aqueous media will depend on the fixation of these elements on the ash particles and pH of the ash-aqueous medium[20]. In addition to this, other factors influencing leaching include ash source and leaching time. In general, under acidic conditions the rate and quantity of leaching is higher. Certain studies reveal that for most of elements present in coal ash, a significant fraction, ranging from 8 % in case of Ni to 17 % in case of Cr, is able to leach[21]. Presently, ash pond lining is not being followed in practice in sites 1 and 2. Therefore, the possibility of leaching of heavy metals increases. In addition to this, dishcarge of rain water and run off from the ash mound areas into surface water bodies can also be a source of water pollution. Therefore, it is necessary to incorporate ash pond lining while designing ash ponds. The shift from wet collection to dry collection system at both the sites is a welcome step, as it will increase the potential of utilization of ash in various applications. One of the disadvantages of using this system is the cost involved, especially in the transportation of fly ash.

A combination of suitable disposal techniques and increased utilization is required to combat the environmental problems associated with CCRs generation.

ACKNOWLEDGEMENTS

One of the authors Mridula Bhatnagar is thankful to the UGC for financial assistance rendered for undertaking Minor Research Project to carry out this research work.

TABLE-7
COMPARISON OF FLY ASH CONTENTS FOUND IN DIFFERENT COUNTRIES

	FA 1 (Present study)	FA 2 (Present study)	Greece[23]	Spain[24]	UK[25]	China[26]	India[20] (average)	Orissa[22] (India)
Cr	102	83	110-160	134.2	Not reported	Not reported	120.0	145.75
Co	17	8	Not reported	29.2	Not reported	Not reported	23.6	16.88
Cu	82	59	31.8-62.8	71.8	Not reported	Not reported	100.0	83.63
Pb	52	33	123-143	52	17-176	843-847	35.0	54.50
Mn	63	140	213-330	324.6	Not reported	Not reported	338.91	338.91
Ni	60	28	Not reported	87.9	Not reported	Not reported	150	56.50
Zn	123	62	59.6	221.3	Not reported	Not reported	Not reported	69.00

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