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Characterizing fly ash particles followed by prediction of removal efficiencies of fly ash and CO_2 in an Indian Wet ESP

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ABSTRACT

In this article, characterization of fly ash particles followed by prediction of removal efficiencies of fly ash and CO_2 by a wet electrostatic precipitator (WESP) attached to a coal fired thermal power plant of M/s CESC Ltd., located in Kolkata, India is reported. The characterization of the fly ash samples collected from the inlet and exit of the WESP as well as from the settling tank includes particle size distribution, Brauner–Emmette–Teller (BET) surface area and pore volume analyses, Fourier transform infra red (FTIR) spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and measuring the pH of fly ash samples. The area mean diameters of the respective samples were 39.73, 4.32 and 12.04 μm. The BET surface areas of the respective samples were 3.292, 3.641 and 9.809 m^2/g. The peaks observed from FTIR analyses of the samples indicated presence of mullite, quartz and silica. The XRD of the samples showed the major mineralogical components as quartz and mullite with traces of lime, hematite and magnetite. The observations made from FTIR, BET and SEM analyses followed the trend of the particle size determined. XRD analyses further followed the results obtained in FTIR analyses. The values of pH of the particles collected from the settling tank before and after alkaline treatment were observed to be 1.45 and 7.12 respectively. Scrubbing of acidic gases was responsible for the reduction of pH in the acidic range. Finally, separate correlations were developed to predict the fly ash and CO_2 removal efficiencies by the WESP as functions of different system variables by multiple non-linear regression analysis. The predicted values agreed well with the measured values (−4.36% and +10% deviations for fly ash and CO_2 removals respectively).

1. Introduction

The existing cyclone separators of a coal fired thermal power station of M/s Calcutta Electricity Supply Corporation (CESC) Ltd., located at Cossipore, Kolkata, India could not achieve the newly promulgated stringent particulate matter (PM) emission standard of 150 mg/Nm^3. As a result, the industry had additionally installed wet electrostatic precipitators (WESPs) alternately to each boiler during 2006–2010 with a view to meet the new standard. The performance of the WESP for collection of fly ash under Indian conditions has already been reported in details in the literature [1]. Fly ash has shown to have various beneficial uses since long back. Fly ash characterization assumes significant importance considering the worldwide problems associated to its disposal. The characterization of fly ash particles collected only from the inlet of the WESP was reported earlier [1]. Therefore, the investigations pertaining to the characterization of coal fly ash reported in the literature are reviewed here for targeting the characterization of fly ash in the present study. Singh and Rawat [2] used FTIR, XRD and SEM analyses for characterizing different fractions of fly ash samples to report on complex characteristics, different fineness, morphology, mineralogical composition, glass content and sphericity of solid, hollow and filled forms. It was reported that these characterizations could be helpful for utilizing huge quantum of fly ash generated from thermal power plants for different purposes as well as adsorbent for wastewater treatment. Panias and Giannopoulou [3] explored fly ash based synthetic geoploymers for construction activities. Construction based activities include building construction, transportation, road, aerospace, mining and metallurgy. The XRD and FTIR analyses were carried out to characterize the fly ash as well as fly ash based geopolymers and reported that the compressive strength of fly ash based synthetic geopolymers would increase with decrease in water content of synthetic geopolymer. Sarkar et al. [4] investigated on the comprehensive characterization of fly ash samples obtainable

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Nomenclature

$C_{CO_2 in}$	Inlet CO_2 concentration, %
C_{FAin}	Inlet fly ash particle concentration, mg/Nm^3
$C_{O_2 in}$	Inlet O_2 concentration, %
D'	Diffusivity of CO_2 in water, m^2/s
d_D	Droplet diameter, m
d_P	Particle diameter, m
D_T	Tube diameter, m
Eu	Euler number, $(\Delta P/\rho_G v_G^2)$, dimensionless;
Re_G	Reynolds number based on gas phase, $(D_T v_G \rho_G/\mu_G)$, dimensionless
Sc	Schmidt number, $(C_{CO_2 in} D'/\mu_G)$, dimensionless
v_D	Droplet velocity, m/s
v_G	Flue gas velocity, m/s

Greek symbols

ρ_g	Gas density, kg/m^3
ρ_L	Liquid density, kg/m^3
ρ_P	Particle density, kg/m^3
μ_g	Gas viscosity, kg/m.s
μ_L	Liquid viscosity, kg/m.s
ΔP	Pressure drop, N/m^2

from thermal power plants of eastern India. The characterization includes percentage weight distribution, particle density, particle size and analyses through XRF, XRD, SEM and FTIR. The informations on coal combustion and on the utilization of fly ash for different purposes were reported. Celik et al. [5] carried out FTIR, XRD and SEM analyses and particle size distribution of different fly ash samples and characterized the chemical properties, physical properties, mineralogical composition and particle size. The characterization of fly ash samples would help in identifying the influence of fly ash on the compressive strength of ordinary Portland cement. Fungaro and Valerio Da Silva [6] deployed different characterization techniques such as XRD, SEM and FTIR analyses of sludge collected from the water treatment plant and coal fly ash. Bricks were made using dried sludge of water treatment plant and coal fly ash for reusing the sludge obtainable from the waterworks and reduce the potential hazards towards disposal of large quantity of coal fly ash.

Current literature on the investigation of WESP is sparse as reported earlier [1]. Briefly, the scanty literatures reported include review of wet electrostatic scrubbing technique for collection of dust or smoke particles [7], performance analysis of a tubular WESP for collection of diesel particulate matter [8], tests for controlling aerosols using a WESP [9], developing an ESP for controlling poultry dust [10], theoretical analysis for predicting the particle removal efficiency in wet electrostatic scrubbers [11], developing a WESP for investigation of collection of corn oil particles [12], performance analysis of a novel ESP for collecting nano-particles [13,14], characterizing the performance of a WESP using various aerosols such as monodisperse polystyrene latex (PSL), polydisperse sucrose, and stearic acid (soft lipid) particles [15], determining the scavenging rate of submicron particles in a WESP [16], evaluating the performance of a WESP for a 0.7 MW oxygen-pulverized coal combustion in terms of the electrical and particle collection [17], performance analysis of a laboratory scale single-stage, single-wire vertical WESP for collecting water droplets [18] and performance analysis of a wire-to-plate single-stage WESP designed to control nanoparticles, submicron and micron-sized particles emitted from semiconductor manufacturing processes [19].

However, detailed characterization of fly ash particles collected from the various sources such as at the inlet and at the outlet of the WESP and from the collection tank before and after alkaline (dilute NaOH) treatment, followed by predicting the removal efficiencies of fly ash as well as CO_2 does not seem to have been reported previously in the literature. In fact, information on these aspects for WESP is not available in the existing literatures. A step by step analysis has therefore, been carried out in this article to report on the characterization of the fly ash particles and fly ash collection as well as CO_2 removal efficiencies based on the WESP fitted into a coal fired thermal power plant.

The characterizations of the fly ash particles collected at the inlet and at the outlet of the WESP as also from the collection tank before and after alkaline (dilute NaOH) treatment are carried out. The samples were collected afresh compared to those reported earlier [1] to generate reproducible data. The characterization includes analyses by particle size distribution, Brauner–Emmette–Teller (BET) surface area and pore volume analyses, Fourier transform infra red (FTIR) spectroscopy, X-ray diffraction (XRD), scanning electron microscopy (SEM) and measuring the pH of fly ash sample collected at various sources by making slurry in distilled water. After the characterization, the scrubbing as well as electrostatic action by the WESP has been investigated in terms of removal efficiencies of fly ash and CO_2. Finally, the overall fly ash collection efficiency and CO_2 removal efficiency are predicted through correlations developed from dimensional analyses followed by multiple non-linear regression analysis as functions of different pertinent variables of the system. In developing the correlations, the stack gas monitored results generated by the plant and other relevant operating variables of the system have been utilized.

2. Materials and methods

2.1. Stack gas monitoring

The stack gas monitoring was comprehensively carried out by the West Bengal Pollution Control Board (WBPCB) over the years following the methods described in Emission Regulations Part III of Central Pollution Control Board [20]. Also the stack gas monitoring following the same method was carried out by the plant which were used in this study. It covers monitoring of stack gas characteristics as well as measurement of concentrations of PM and CO_2. The relevant results are used gathering from WBPCB for the purpose of this study.

2.2. Characterization of the fly ash samples collected from various sources

The fly ash samples were collected from inlet to WESP, outlet to WESP and from the settling tank before and after alkaline (dilute NaOH) treatment. The samples were collected from a single WESP assuming the samples would be representative since coal used was same and the WESPs installed were identical. The schematic of the WESP is shown in Fig. 1. The settling tank was used for collection of the slurry produced by the in-situ wet scrubbing action, in addition to the electrostatic action of the WESP, for the collection of the fly ash particles. Water was used in the WESP for introducing the wet action. No alkaline reagent was used for this purpose. Dilute NaOH solution was only used for neutralizing the scrubbed slurry outside the WESP prior to disposal. A process flow diagram describing the steps of emissions from a coal fired thermal power plant, WESP, tank system for neutralizing the slurry pH and the stack is shown in Fig. 2 for improved understanding. The detailed methods of characterization of the samples are presented in Table 1.