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Fly Ash Characterization and Prediction of Fly Ash and CO_2 Removal Efficiencies for Indian Wet ESP

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Abstract

This article reports on the characterization of fly ash collected from the wet electrostatic precipitator (WESP) installed as air pollution control devise to an Indian coal fired thermal power plant. The samples were collected from various points such as the inlet and the outlet of WESP as well as from the settling tank of collected ash slurry. The characterization includes various analyses such as particle size distribution, Brauner-Emmette-Teller (BET) surface area and pore volume analysis, Fourier Transform Infra Red (FTIR) Spectroscopy, X-ray diffraction (XRD), Scanning Electron Microscopy (SEM) analysis and measuring the pH of fly ash samples collected from the various sources in distilled water. Finally, separate correlations were developed in order to predict the fly ash and CO_2 removal efficiencies by the WESP as a function of different system variables by multiple non-linear regression analysis. The predicted values were in excellent agreement with the measured values.

Keywords: Characterization, Fly Ash, Fly Ash and CO_2 Removal, Wet ESP

1. Introduction

Fly ash characterization assumes significant importance considering the worldwide problems associated to its disposal. Fly ash has shown to have various beneficial uses since long back. Some of the investigations pertaining to the characterization of coal fly ash are reviewed here for targeting the characterization of fly ash in the present studies. Singh and Rawat[1] used FTIR, XRD and SEM analyses for characterizing different fractions of fly ash samples to report on their complex characteristics. Panias and Giannopoulou[2] explored fly ash based synthetic geoploymers for construction activities using XRD and FTIR analyses. Sarkar et al.[3] investigated on the comprehensive characterization of fly ash samples obtainable from thermal power plants of eastern India through XRF, XRD, SEM and FTIR analyses. Celik et al.[4] 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. Fly ash collected from the WESP at various sources were however, not reported earlier.

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Current literature on investigation of WESP include review of wet electrostatic scrubbing technique for collection of dust or smoke particles[5], performance analysis of a tubular WESP for collection of diesel particulate matter[6], tests for controlling aerosols using a WESP[7], developing an ESP for controlling poultry dust[8], theoretical analysis for predicting the particle removal efficiency in wet electrostatic scrubbers[9], developing a WESP for investigation of collection of corn oil particles[10], performance analysis of a novel ESP for collecting nano-particles[11,12], characterizing the performance of a WESP using various aerosols such as monodisperse polystyrene latex (PSL), polydisperse sucrose, and stearic acid (soft lipid) particles[13], determining the scavenging rate of submicron particles in a WESP[14], evaluating the performance of a WESP for a 0.7 MW oxygen-pulverized coal combustion in terms of the electrical and particle collection[15], performance analysis of a laboratory scale single-stage, single-wire vertical WESP for collecting water droplets[16] 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[17]. These literatures do not report on the removal efficiencies of fly ash as well as CO_2. These gaps in the literature are filled in this article.

2. Methodology

The characterization includes analyses by particle size distribution using LASER diffraction technique in a Microtrac (make S3500, USA) particle size analyzer, BET surface area and pore volume analysis (Autosorb 1C, Quantachrome Instruments, USA), FTIR Spectroscopy (IR Prestige – 21, SHIMADZU, JAPAN), XRD (Rigaku model, Japan), SEM (Model Evo–18, Special Edition, Carl Zeiss, West Germany) and measuring the pH of fly ash sample collected at various sources by making slurry in distilled water. The XRD were carried out with CuKα radiation (λ = 0.15406 nm) operating at 15 mA and 30 kV. The data were collected in the scan range of $3° < 2\theta < 80°$, with a sampling width of 0.04° and scan speed of 1°/min. Finally, the overall fly ash collection efficiency and CO_2 removal efficiency are predicted through correlations developed from dimensional analyses. In developing the correlations, the stack gas monitored results generated by the plant and other relevant operating variables of the system have been utilized.

3. Results and Discussion

3.1 Characterization of Fly Ash Particles

The particle size distributions of the fly ash samples collected from various sources were carried out using LASER diffraction technique. The particle size distributions (Figure 1) of the fly ash samples collected at the inlet (Dust-I) and outlet of the WESP (Dust-O) as well as from the settling tank after alkaline treatment (Dust-T) are done. Highest value could be observed for the sample collected at the inlet of the WESP, while lowest value could be observed for the sample collected at the outlet of the WESP. The values of D_{50} (i.e., cut diameter at 50% collection efficiency) were 7.33, 26.18 and 52.44 μm for Dust-O, Dust-T and Dust-I respectively.

The surface area and the pore volume of the samples were measured by BET method using surface area analyzer. The measured values of the surface area of the fly ash samples collected at the inlet and outlet of the WESP as well as from the settling tank (after alkaline treatment) were 3.292, 3.641 and 9.809 m^2/g respectively. The increase in the surface area from the inlet sample to the outlet sample could be attributable to the collection of relatively larger particles by the WESP and emitting the smaller ones. Alkali treatment might have influenced in increasing the surface area possibly by both internal and external surface modifications as well as due to the dissolution of particles. The measured values of pore volume of the respective samples were 0.0013, 0.0014 and 0.0067 cc/g.

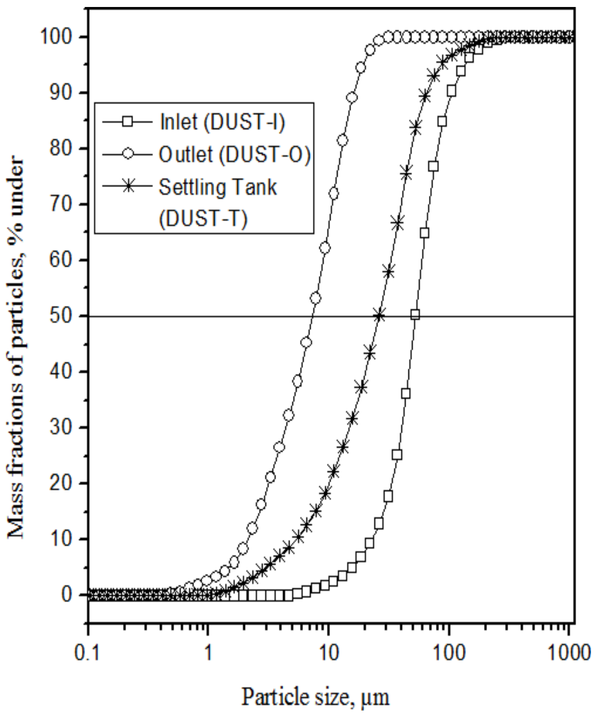

Figure 1. Size distribution of fly ash particles showing the variation of different cut diameters of the fly ash samples.

The FTIR analyses of the samples were carried out with the help of a spectrophotometer in the range of 400 and 4000 cm^{-1}. Peaks observed in the frequency range of 3628.10 cm^{-1} to 3697.54 cm^{-1} for the presence of stretching band of –OH from lime as one of the mineral materials for Dust-I and Dust-T. All three samples showed peaks in the range of 1080.14 cm^{-1} to 1091.71 cm^{-1} due to asymmetric stretching vibrations of Si–O–Si and Al–O–Al of SiO_2 and Al_2O_3 respectively. The typical presence of mullite materials in three fly ash samples in the frequency range of 1047.35 cm^{-1} to 1091.71 cm^{-1} was assigned to Si–O–Si / Si–O stretching and these peaks were called mineral peaks. For Dust-T, a band was observed at 966.34 cm^{-1} perhaps due to the formation of alumino-silicate by the dissolution of fly ash in alkaline (NaOH) medium. In all the samples, a band observed around 800 cm^{-1} could be due to the presence of quartz.

The Mineralogical compositions of the samples were determined by X-ray diffractometer. The XRD pattern of the sample collected at the inlet to the ESP is shown in Figure 2. The diffractograms of the samples showed several distinct peaks with the identification of minerals as quartz, mullite, lime, hematite and magnetite.

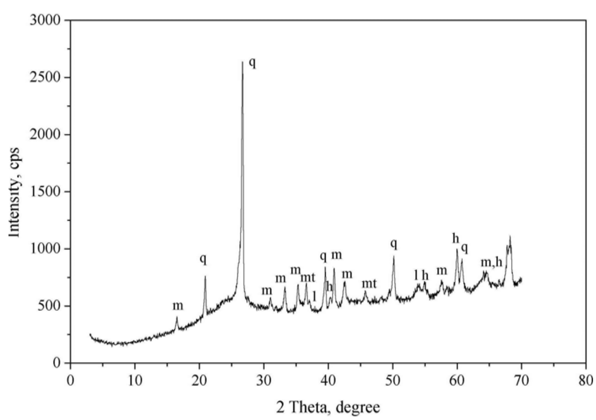

Figure 2. XRD pattern of fly ash samples collected at the inlet of the WESP.

The surface morphologies of the samples were characterized using the SEM (Figure 3). The images of these samples showed solid and some hollow particles of variable sizes. In general, the size was decreased from Dust-I to Dust-T and from Dust-T to Dust-O in conformity to particle size analysis and BET analysis.

The values of pH of the fly ash samples collected at the inlet and outlet of the WESP as well as from the settling tank before and after alkaline treatment were measured in distilled water. The values of pH were reducing with the increase in the weight of the fly ash particles in all the samples. The samples collected at the inlet and at the outlet shown to offer final pH value of about 7.32 and 6.26 respectively. It could be perhaps due to the dissolution of acidic components adsorbed within the fly ash particles. The pH of the particles collected from the settling tank after alkaline treatment was observed to be 7.12 and was marginally lower than that observed in the case of the particles collected at the inlet. The particles were alkali treated in the settling tank to raise the pH level of the slurry.

3.2 Prediction of Removal Efficiencies

An attempt has been made to correlate the overall collection efficiency of fly ash particles with the various pertinent variables of the system by dimensional analysis. Multiple non-linear regression analysis was carried out to determine the best possible correlation (at 99.0% confidence range with correlation coefficient of 0.9917 and coefficient of determination of 0.9835) as follows

$$\eta_{FA} = 1 - 1.0\left[Re_G^{0.56}.Eu^{-0.747}.\left(\frac{d_P}{D_T}\right)^{-0.1404}\left(\frac{C_{FAin}}{\rho_P}\right)^{-0.5563}.\left(\frac{C_{CO_2in}}{C_{O_2in}}\right)^{-1.2737}\right] \quad (1.1)$$

The predicted values agreed excellently well with the measured values (- 4.36 % deviation). An attempt has also been made to correlate the overall CO_2 removal efficiency with the various pertinent variables of the system through dimensional analysis. Multiple non-linear regression analysis was carried out to determine the constant and coefficients of the equation that presents the best possible correlation (at 99.0% confidence range with correlation coefficient of 0.9692 and coefficient of determination of 0.9394) as follows

$$\eta_{CO_2} = 1 - 1.0\left[Re_G^{-0.0046}.Eu^{-0.0035}.Sc^{-0.0016}\right] \quad (1.2)$$

The predicted values agreed excellently well with the measured values (+ 10% deviation).

4. Conclusion

The characterization of fly ash collected from the wet electrostatic precipitator (WESP) installed as air pollution control devise to an Indian coal fired thermal power plant followed by prediction of removal efficiencies of fly ash and CO_2 were reported in this article. The samples were collected from various points such as the inlet and the outlet of WESP as well as from the settling tank of ash slurry. The characterization of fly ash samples was carried out by various analyses such as particle size determination, BET, XRD, FTIR, SEM analyses and pH measurement. The interrelationships amongst some of the analyses were also elucidated. The fly ash and CO_2 removal efficiencies were predicted through two different

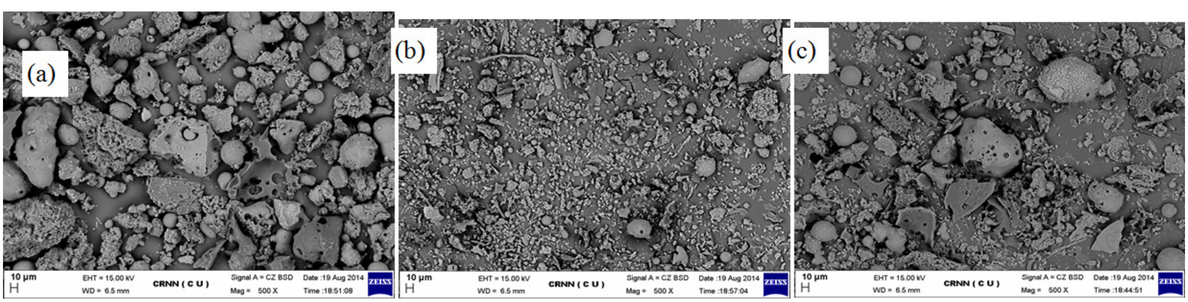

Figure 3. SEM images of fly ash samples collected at the (a) inlet, (b) outlet of the WESP and (c) from the settling tank after alkaline treatment.

correlations using multiple non-linear regression analyses as functions of various pertinent variables of the system which were statistically highly significant.

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