Influence of flue gas conditioning on fly ash characteristics

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abstract
In this technical note an effort has been made to investigate the influence of flue gas conditioning, FGC, on physical, chemical, mineralogical and morphological characteristics of the fly ash. FGC is a technique that involves addition of chemical additives to the flue gas, for increasing the ash collection efficiency of electrostatic precipitators, ESPs. The FGC also helps in reducing the amount of suspended particulate matter, SPM, which is released into the surrounding environment at thermal power stations. It is a well established fact that utilization of the fly ash, as a cementitious material, depends on its pozzolanic characteristics, which in turn pivots on its physico-chemico-mineralogical and morphological characteristics. However, how these characteristics get influenced due to FGC has not yet been reported in the literature.

With this in view, ash samples from a coal-fired thermal power station in India, where flue gas conditioning is being employed, were collected and their physico-chemico-mineralogical and morphological properties were examined. Based on these studies efforts have been made to highlight the influence of FGC on ash characteristics.

1. Introduction
Fly ash particles that are in the form of suspensions in the flue gas contribute to an increased suspended particulate matter, SPM, in the surrounding environment. As such, for safeguarding the environment, reduction in emission levels of the SPM becomes essential. To achieve this, several pollution control devices such as cyclone separators, bag filters and electrostatic precipitators, ESPs, are being employed. Though, cyclone separators [1–17] and bag filters [3,8,10,18–23] are employed to remove the particulate matter from the flue gas, these techniques have their own limitations. On the other hand, ESPs are most popularly used at thermal power stations [2–4,10,24–40] to reduce SPM levels. This is mainly due to their: (i) higher efficiency of removal of particles (<0.01 μm in size), (ii) effectiveness over wide range of operating temperatures, and (iii) suitability for corrosive environmental conditions.

It has also been demonstrated by earlier researchers [18,20,26] that the performance of ESP can be improved by: (i) changing the feed coal characteristics, (ii) increasing the collection plate area to the existing ESP, (iii) employing wet ESP to minimize re-entrainment, (iv) increasing or lowering the gas temperature, and (v) addition of chemicals to modify the fly ash or the electrical conditions in the ESP. However, most of these options are difficult to be implemented at a thermal power station, mainly, due to the fact that: (i) there are constraints associated with the feed coal (i.e., cost associated with import, washing of the coal and environmental issues associated with it, and ash content etc.), (ii) addition of more collection plate area in ESP, which requires more space and is highly expensive, (iii) the installation and operating costs for employing wet ESPs is too high apart from lump formation of the ash and its degradation as a construction material [41–42].

Under these circumstances, the flue gas conditioning, FGC [2,20,37,43–56] becomes inevitable. FGC is a technique that involves addition of chemical additives to the flue gas in order to increase ash collection efficiency of electrostatic precipitators, ESPs. Based on the critical review of the literature, it has been observed that FGC has several advantages such as: (i) less cost involved as compared to establishment of additional ESPs, (ii) less time requirement for execution, (iii) more flexible and versatile to adopt i.e., even with variations in the operating parameters (such as coal characteristics, boiler load, ESP voltage and current change occur), SPM levels can be easily controlled to the desired level by simply adjusting the dosing amount of the FGC agents. These agents are quite helpful in improving the surface conduction characteristics of fly ash/dust particles, which results in enhanced ash collection efficiency of the ESP.

It is well known that utilization of the fly ash, as a cementitious and pozzolanic material, depends on its pozzolanic characteristics, which in turn pivots on its overall (physico-chemico-mineralogical and morphological) characteristics [42,57–68]. However, how
these characteristics of the fly ash get influenced due to FGC has not yet been reported in the literature.

With this in view, fly ash samples were collected from a thermal power station, in India, where flue gas conditioning is being employed to reduce SPM levels successfully. These samples were tested for their physical, chemical, mineralogical and morphological characteristics. Based on these studies attempts have been made to highlight the influence of FGC on fly ash characteristics.

2. Experimental investigations

2.1. Material

Fly ash samples were collected from a coal-fired 210 MW capacity thermal power station, in India. These samples, depicted as* in Fig. 1 corresponds to different hoppers in ESP (field wise, depicted as F1–F5, and A–D correspond to flow paths), were collected when the power station is operated without and with different concentrations of FGC agent (Ammonia in the present study). Details of the samples along with their designation are presented in Table 1. Details of various tests conducted on each of these samples are presented in the following.

2.2. Physical characterization

The sample was analyzed for its specific gravity, G, by using an Ultra-Pycnometer (Quantachrome, USA), which employs Helium gas [69]. The specific surface area, $S$, of the sample was determined by employing Blaine’s air permeability apparatus [70] and Portland cement was selected as the standard reference material. The results are presented in Table 2.

The particle size distribution characteristics of the fly ash sample were obtained by conducting fine sieve analysis followed by hydrometer test [71]. However, for the sake of brevity, results for samples 0F1-II to 0F5-II and 35F1 to 35F5, only, are being presented in Table 1. Details of various tests conducted on each of these samples are presented in the following.

![Fig. 1. Schematic of sampling locations in the ESP.](image)

### Table 1
Details of the samples

<table>
<thead>
<tr>
<th>Concentration of ammonia (kg/hr)</th>
<th>Collection point</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Field 1</td>
<td>0F1-I</td>
</tr>
<tr>
<td></td>
<td>Field 2</td>
<td>0F2-I</td>
</tr>
<tr>
<td></td>
<td>Field 3</td>
<td>0F3-I</td>
</tr>
<tr>
<td></td>
<td>Field 4</td>
<td>0F4-I</td>
</tr>
<tr>
<td></td>
<td>Field 5</td>
<td>0F5-I</td>
</tr>
<tr>
<td>35</td>
<td>Field 1</td>
<td>35F1</td>
</tr>
<tr>
<td></td>
<td>Field 2</td>
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<td></td>
<td>Field 5</td>
<td>50F5</td>
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</tbody>
</table>

* FGC agent.
In addition, the percentage by weight of the fly ash, retained on ASTM sieve No. 325 (45 μm), R45, was determined by following the procedure presented by ASTM C 311-05 [72]. The results are presented in Table 2. Using the particle size distribution characteristics depicted in Fig. 2, different size fractions such as clay size (<2 μm), silt size (2–75 μm) and sand size (>75 μm), present in the sample, were obtained and are listed in Table 2.

### 2.3. Chemical characterization

pH and electrical conductivity (EC) of the sample was measured by using a water quality analyzer (Model PE 136, Elico Ltd., India). Liquid to solid (L/S) ratio of 20 was achieved by mixing 5 g of the oven dried sample with 100 ml of distilled water. This mixture was stirred, continuously, for half an hour and the pH and EC of the filtrate was determined. These results are presented in Table 3.

Chemical composition of the sample, in the form of major oxides, was determined using an X-Ray Fluorescence (XRF) setup, (Phillips 2404, Holland). Details of the sample preparation are presented in the following. Four gram of fly ash sample, 1 g of microcrystalline cellulose and isopropyl alcohol were mixed thoroughly, and the mixture was kept below an infrared lamp for slow drying. A small aluminum dish (with inner diameter of 33 mm and height of 12 mm) was taken and one third of this dish was filled with methyl-cellulose, followed by filling up the container by the dried sample. The sample was compressed with the help of a hydraulic jack and the chemical composition of the sample was determined by mounting the compressed dish (pellet) in the sample holder of the XRF setup. The results are presented in Table 4.

### 2.4. Mineralogical characterization

The sample was evaluated for its mineralogical characteristics by employing X-Ray diffraction spectrometer (Phillips 2404, Holland) studies, using a graphite monochromator and Cu Kα radiation. The sample was scanned from 2θ ranging from 5° to 80°. The presence of minerals has been confirmed with the help of the data files presented by the Joint Committee on Powder Diffraction Standards [73]. It was found that various crystalline phases of minerals present in fly ashes are Quartz, mullite and hematite, among which, Quartz is the major phase. There is no appreciable
Fig. 3. Micrographs of different samples.

Fig. 4. Specific gravity of different samples.

Fig. 5. Specific surface area of different samples.
difference between the mineralogy of the conditioned and unconditioned ash samples.

2.5. Morphological characterization

Morphology of the sample was studied by employing a scanning electron microscopy (Hitachi S3400N, USA). The sample was coated with gold to avoid charge effect. Later, the sample was placed in a sample holder and the images were captured, under various magnifications. Morphological characteristics of various samples are depicted in Fig. 3.

3. Results and discussion

The specific gravity, $G$, and specific surface area, $S$, of various samples were plotted against various fields, as depicted in Figs. 4 and 5, respectively. It can be observed from these figures that both $G$ and $S$ are minimum and maximum for F1 and F5, respectively. This indicates that coarsest particles get collected in the field F1 (nearest) while the finest particles get collected in the field F5 (farthest), respectively. These observations are consistent with the results reported in the literature [74–77] and the trends depicted in Fig. 2. It can also be noted that there is no significant difference between the values of $G$ and $S$ for conditioned and unconditioned samples.

A further analysis of the data presented in Fig. 2 is depicted in Fig. 6, which highlights the influence of ammonia dosing on particle size fractions present in the fly ash collected from different fields. It can be noted from the figure that Field F1 is most sensitive to ammonia dosing as compared to other fields. For this field, the percentages of silt sized and sand sized fractions are least and most, respectively, as compared to other fields. This leads to an increase in the percentage of clay sized fraction in Field 5 as compared to other fields. Incidentally, as depicted in Fig. 7, the percent retained on 45 $\mu$m size sieve (ASTM No. 325) is found to be much more for Field F1 as compared to Field 5, which is the farthest field. This indicates conglomeration, and hence increase in effective size, of the ash particles due to ammonia dosing. In order to confirm this, SEM micrographs of the conditioned and unconditioned fly ash samples, depicted in Fig. 3, were used. It can be observed from Fig. 3a,b that the unconditioned fly ash sample contains spherical, near spherical, platelets, irregular shaped particles, broken spheres filled with smaller spheres, known as

![Figure 3](image-url)

Fig. 3. SEM micrographs of the conditioned and unconditioned fly ash samples.
pleurospheres. However, from the SEM micrographs of the conditioned fly ash samples, Fig. 3c–f, agglomeration of the ash particles can be noticed. This can be attributed to the formation of ammonium salts which are responsible for binding (increased cohesion) fly ash particles [56]. This process results in an increased collection efficiency of the ESP, which in turn results in less SPM level. Fig. 8 indicates that there is no significant difference between the pH and EC values of the conditioned and unconditioned fly ash samples. As such, ammonia conditioning of the fly ash does not alter its chemical properties, which also gets substantiated by the XRF results presented in Table 4.

4. Concluding remarks

This technical note presents details of the investigations conducted on conditioned and unconditioned fly ash samples, collected from a coal based power station in India, where flue gas conditioning is being practiced. The study reveals that the conditioning of the ash with ammonia does not alter its physico-chemical-properties. However, from the SEM micrographs of the conditioned fly ash samples, the agglomeration of the ash particles can be observed very clearly, which results in a reduced collection efficiency of the ESP, which in turn results in less SPM level. However, similar studies from different power stations, where different conditioning agents are being used, should be conducted for generalization of the findings.

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