Leaching Characteristics of Heavy Metal in Bottom Ash from Indian Thermal Power Plant

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The disposal of bottom ash in the thermal power plant is a challenging task. The objective of the present study was to investigate the leaching characteristics of the bottom ash disposed in ash pond of thermal power plants. The studies were conducted with bottom ashes from ash disposal system. A series of leaching test have been performed with different liquid to solid ratio (L/S). The (L/S) varies from 20:1 to 60:1. It is observed that the elements of Mn, Mg, Cr, Zn, Ni, and Cu are most abundant elements while Pb, Mo, Fe and Co are the least abundant elements. It is also observed that the leaching characteristics of the bottom ash are affected by the pH of extraction solution and liquid to solid (L/S) ratio.

Keywords: Leaching Characteristics, Bottom Ash, Ash Disposal, Thermal Power Plants, Trace Elements

Introduction

In India, about 70% electricity generation produced by combustion of pulverized coal in thermal power plants. The Indian coal having very high ash content and low calorific value, generate the large quantities of ash produced as by-products of combustion. During the combustion process of coal, some tracing elements like Cr, Fe, Ni, Cu, Cd, Pb etc are leached out from the solid phase. The trace elements also associated on the surface of the ash particles, in the condensation and evaporation process. The tracing elements present in coal ash migrate to ground water, surface water and soil over a period of time. The production of the large amount of the toxic metal elements in ash disposal system of the thermal power plants can pose negative environmental effects on human health and on plants. In the present study, an attempt has been made to investigate the leaching characteristics of the bottom ash disposed in the ash pond in order to predict the environmental effect from the ash disposal on the ground water quality.

Materials and methods

Bottom ash used for leaching experiments were collected from the ash pond of four different thermal power plants namely Guru Nanak Dev thermal power station, Bhatinda, Punjab, Guru Gobind Singh Super Thermal Power Plant, Ropar, Punjab, Guru Hargovind thermal power plant, Lehra Mohabbat, Punjab and Deenbandhu Chhotu Ram thermal power plant, Yamunanagar, Haryana and labeled as S-I, S-II, S-III and S-IV. The chemical composition and morphology of the bottom ash samples was determined using Scanning electron microscopy-energy dispersive X-ray spectroscope (Model: JEOL, 6510LV). The leaching characteristics of the coal ash samples were determined by using TCLP method. The Remi orbital shaking lubricator (Model: RS 12 plus) was used for shaking of the solution. All the tracing elements were analyzed by using atomic absorption spectrophotometer (AAS 4129, make- ECIL, India) following the standard methods (APHA, 1995).

Result and Discussion

Physical and chemical characteristics

The pycnometer method was used to determine the specific gravity of ash samples. The specific gravity of the bottom ash samples of S-I, S-II, S-III and S-IV were found as 2.25, 2.18, 2.31 and 2.15. The particle size distribution of collected ash samples were determined by using sieve analysis. The biggest particle size of bottom ash were determined as 1400 μm, 710 μm, 1000 μm, 710 μm in the sample of S-I, S-II, S-III and S-IV. The weighted mean diameter of bottom ash particles were found as 158 μm, 154 μm, 162 μm and 149.20 μm for sample S-I, S-II, S-III and S-IV respectively. The static settled concentrations of the bottom ash slurries were determine by taking

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mixture of 20% concentration (by weight). The final value of static settled concentration of bottom ash slurries were found as 50.20, 49.50, 47.65 and 52.56 % (by weight) for sample S-I, S-II, S-III and S-IV respectively.

The pH values have been measured at various concentrations in the range of 10 to 60% (by weight). The pH value of coal ash varies with the solid concentration in the range of 6.60 to 6.21, 6.50 to 6.00, 6.55 to 6.19 and 6.85 to 6.31 for sample S-I, S-II, S-III and S-IV respectively. The pH values of samples depict reactive nature of all the ash slurries.

Mineral and morphological characteristics

The XRD results of the samples of S-I, S-II, S-III and S-IV are shown in Figure 1(a-d). The XRD results show that the major crystalline phases identified in all collected bottom samples (S-I, S-II, S-III & S-IV) are quartz and mullite whereas the hematite is identified only in sample S-I. It is also observed that bottom ash particles are coarser, darker grey in color due to the presence of unburned carbon, irregular and having rough surface texture. The values of quartz, mullite and hematite are 53.7%, 44.2% and 2.1% in sample S-I whereas the values of Quartz and Mullite in sample S-II, S-III, S-IV are 49.00% and 51.00%, 51.00% and 49.00%, and 54.00% and 46.00% respectively. The hematite is present in small amount in sample S-I. The chemical composition of quartz is SiO₂, composition of mullite is Al₄(4+2x)Si₂(2-2x)O₁₀-x where the value of x lies between 0.17-0.59 and composition of hematite is Fe₂O₃. The strong peak due to quartz in samples S-I, S-II, S-III and S-IV are in close proximity to 26.59°, 26.55°, 26.52° and 26.57° similarly the peak due to mullite are in close proximity 26.23°, 26.23°, 26.19° and 26.20° in bottom ash samples. Energy-dispersive X-ray spectroscopy (EDX) was used to measure the chemical compositions of bottom ash samples. It is observed that in all the samples, the proportion of aluminum oxide and silica oxide are more as compared to other elements like iron (Fe), titanium (Ti), potassium (K), calcium (Ca), magnesium (Mg), zinc (Zn) etc. The percentage of silica oxide and aluminum oxide in samples S-I, S-II, S-III and S-IV 51.21 and 37.46%, 52.68 and 40.29%, 48.54 and 43.67% and 45.26 and 41.54% respectively. This shows that these particles have a high surface enrichment of aluminum (Al) and Silica (Si), causing drag effects on the flow behavior of the bottom ash slurry 2,4,12-14. The bottom ash with reasonable proportion of silica and alumina can be utilized as a raw material for synthetic alumino-silicate aggregates for refractory and ceramic applications 8-11. The silica shows presence in major proportion in the form of quartz which improves the strength of the support materials and used in construction industry as a building materials 10-12. The presence of high proportion of silica in bottom ash improves the strength and presence of CaO gives the cementing properties. Hence bottom ash also can be used utilized as a stowing material in underground coal mines 3, 5, 11-13.

Leaching characteristics

The results of leaching tests for the bottom ash sample of S-I, S-II, S-III and S-IV are presented in Table 1. The tracing elements like manganese (Mn), nickel (Ni), magnesium (Mg), chromium (Cr), zinc (Zn), copper (Cu), lead (Pb), cobalt (Co), iron (Fe), and molybdenum (Mo) were determined by TCLP method. The (L/S) ratio was taken 20:1, 40:1 and 60:1. Leaching is the most likely process by which coal ash constituents would become environmental contaminants 9-11. The quantity of elements in leaching depends on the pH value of aqueous medium and ash constitutes. It has also been reported that the trace element composition in coal ash even from a single thermal power station may vary even on daily measurements. In the bottom ash sample S-I, at L/S ratio 20:1 the leaching order for heavy tracing element have been found as Mg>Mn>Zn >Cr>Cu>Ni>Pb>Fe>Co>Mo whereas in the sample S-II, S-III and S-IV the order of tracing element found as Mg>Mn>Cr >
Table 1–Concentration of different leached elements in bottom ash samples with variation of liquid to solid ratio

<table>
<thead>
<tr>
<th>Bottom Ash Sample</th>
<th>S-I</th>
<th>S-II</th>
<th>S-III</th>
<th>S-IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>L/S Ratio</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>Mn</td>
<td>62</td>
<td>68</td>
<td>75</td>
<td>55</td>
</tr>
<tr>
<td>Mg</td>
<td>80</td>
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<td>92</td>
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<td>Cr</td>
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<td>54</td>
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<td>Zn</td>
<td>46</td>
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<td>50</td>
<td>40</td>
</tr>
<tr>
<td>Cu</td>
<td>22</td>
<td>28</td>
<td>33</td>
<td>20</td>
</tr>
<tr>
<td>Ni</td>
<td>15</td>
<td>28</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Pb</td>
<td>11</td>
<td>15</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>Co</td>
<td>3</td>
<td>3.5</td>
<td>6</td>
<td>2.5</td>
</tr>
<tr>
<td>Fe</td>
<td>11.5</td>
<td>14.5</td>
<td>15</td>
<td>9.5</td>
</tr>
<tr>
<td>Mo</td>
<td>1.5</td>
<td>1.62</td>
<td>1.75</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Zn>Cu>Ni>Pb>Fe>Co>Mo, Mg>Mn>Cr>Zn>Cu>Ni>Pb>Fe>Co>Mo. In the sample S-I, S-II, S-III the maximum leachibility observed as Mg whereas in sample S-IV, Mn found as maximum leachate element. The heavy metal element Mo showed minimum leach concentration in all the bottom ash samples. From the leaching test data of the bottom ash sample S-I, it is observed that the leachate concentration of the tracing element increases with increase in liquid-solid (L/S) ratio. The tracing element concentration of manganese (Mn), magnesium (Mg), chromium (Cr) zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), cobalt (Co), iron (Fe), and molybdenum(Mo) increases from 60.00 to 72.05, 80.00 to 90.68, 42.75 to 52.35, 43.80 to 49.67, 20.00 to 30.85, 13.72 to 23.45, 10.64 to 16.58, 3.00 to 5.56, 10.80 to 14.68 and 1.64 to 1.79 mg/Kg, with the variation of (L/S) ratio from 20:1 to 60:1. The tracing element result data of bottom ash sample S-II, S-III and S-IV show the similar nature of leaching characteristics as sample-I. In the sample S-II, tracing element concentration increases from 55.00 to 66.00, 71.00 to 84.04, 50.55 to 64.87, 40.81 to 53.50, 20.56 to 30.50, 19.04 to 24.56, 10.50 to 24.87, 2.52 to 4.20, 9.50 to 13.30 and 1.20 to 2.05 mg/Kg whereas in sample S-III, concentration increases from 65.00 to 75.50, 73.48 to 82.40, 41.15 to 52.58, 44.40 to 57.15, 26.20 to 35.40, 17.58 to 22.15, 13.50 to 18.05, 2.05 to 4.10, 13.50 to 16.78 and 1.50 to 2.25.In the sample S-IV concentration increases from 55.68 to 64.50, 69.23 to 79.50, 48.75 to 63.45, 36.20 to 49.15, 26.58 to 38.15, 18.10 to 30.30, 8.10 to 13.50, 4.10 to 5.50, 7.50 to 12 and 1.30 to 1.65 mg/Kg. From the leaching results of the bottom ash sample S-I,S-II and S-III data, it is observed that the tracing elements of Mn, Mg, Cr, Zn, Ni, Pb, Fe and Cu are most abundant elements while Mo and Co are the least abundant elements, present in the range of 1.50–9.60 mg/kg. Similar type of analysis results have been reported in the literature with coal ash of different thermal plants$^2,4,7,8$. Minimum leachibility of the solution was observed with the (L/S) ratio 20:1, whereas maximum leachibility of the solution was observed with (L/S) ratio 60:1. Similar result has been reported by investigators$^8,9,11$. The effect of the leaching characteristics from the bottom ash waste was determined in water of the nearby village of thermal power plants, which is shown in Figure 2. Total ten elements; have been traced out from the collected water. The elements Zn, Mo and Co show under the prescribed limits of the drinking water$^{15}$ and elements...
Mg, Cr, Pb, Mn, Ni, Cu and Fe have crossed the standard limits. These elements may cause many harmful effects on the human health like heart attack, damage of nervous systems, lung tumors and liver failure etc. The conventional ash transportation system can be replaced with high concentrated ash disposal which control the production of leachate\textsuperscript{7,9,11-12} by controlling the operational parameters of combustion process such as temperature, air flow etc also can be minimizing the leaching concentration.

**Conclusions**

Based on the present investigation on the leaching characteristics of the bottom ashes of four different thermal power stations, the following conclusions were drawn:

- Bottom ash is disposed of in the land with high environmental risk. Improper disposal of the bottom ash can cause the contamination of ground and surface water.
- The tracing element concentrations of the metal in the bottom ash also show the variations from one plant to the other one.
- The tracing elements Mn, Mg, Cr, Zn, Ni, Pb, Fe and Cu are found most abundant elements while Mo and Co are the least abundant elements.
- The concentration of heavy metal elements viz Zn, Mo and Co is within the permissible limits of Indian standard\textsuperscript{15} while elements of concentrations of elements Mg, Cr, Pb, Mn, Ni, Cu and Fe have crossed the standard limits. These may cause many harmful effects on the human health.

**References**