CHAPTER 6

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The coal combustion thermal power plants all over the world are major sources of electricity that generate huge quantities of fly ash as a by- product during the combustion of coal. About 160 million tons of fly ash is produced each year in India, of which approximately 63% is utilized beneficially. With the growing concern about pollution and increasing landfill costs, the study on the utilization and application of fly ash has increased worldwide. The morphology and the particle size of fly ash make it suitable for application as filler in polymers, but its application is hampered by the lack of compatibility between the organic matrix of the polymer and the inorganic surface of the ash. Another concern is the agglomeration of fly ash particles. For this reasons, the surface treatment is generally carried out in mineral fillers to improve the workability and compatibility between the polymer and filler. In recent years, a large amount of fly ash has been used in various sectors, such as construction, construction engineering, roads, landfills and agriculture.

Despite its many desirable geotechnical characteristics, it contains a large amount of heavy metals. The fraction of fine particles of fly ash could be enriched in trace elements with respect to the fraction of trace elements in the parent coal. This is due to the volatilization of some elements in the boiler and their subsequent condensation in the cooler sections of the flue gas stream. In many of the most toxic elements, considerable enrichment is observed in the fine particle of fly ash (Govindan et al., 2010). Karayigit et al., 2005 reported that some volatile elements, in particular As, Cd and Zn, had increasing concentrations of fly ash from coarse to fine particle size. Similar observations with As, Cd, Pb and Zn have also been reported by Hower et al., 2001. Due to the presence of toxic elements in a large amount of fly ash, the disposal of fly ash has drawn attention with regard to public health and the environment. Since conventional methods for disposal of fly ash, either in landfills by dry disposal system or in an ash pond by wet disposal system. These metal ions are easily released into an aqueous environment, causing future threats to the environment. The leaching of fly ash during the disposal of the plant is a source of major environmental concern for the possible contamination of surface and groundwater, soil and sediments. The unmanaged disposal of fly ash can cause significant problems for the ecology and environment. During disposal the leaching of fly ash is of concern for possible contamination, especially for the aquatic environment, when the fly ash is in direct contact with water. In the construction of the ash pond, the lining of the ash pond is not used. Therefore, fly ash is disposed of in ash ponds with high environmental risk and the possibility of leaching of heavy metals increases. Since the soil under the reservoirs is always saturated and under considerable hydraulic head, the ponds that are improper lined offer a great opportunity for contamination groundwater. Surface water contamination can also occur due to surface run off from ash ponds. The nature of effluents, the solid -liquid ratio, pH of leachant and contact time determines the leachability of elements associated with fly ash. A combination of appropriate disposal techniques and increase in utilization of fly ash appears to be necessary steps to combat the environmental problems associated with the generation of fly ash and their safe disposal. Promotion of increased use of fly ash in construction activities, appropriate disposal practices must be undertaken with better management to minimize the negative impacts of fly ash on the surrounding environment.

It is evident that the fly ash utilization in the engineering application is extremely useful as well as being effective in disposal of the increasing production of fly ash due to rapid growth of industrialization and urbanization. Fly ash has become an attractive construction material because of its pozzolanic character. The fly ash has proved to be a promising material for utilization in various sectors such as cements, bricks, blocks, road construction and concrete materials etc. However, a frame works to analyze and evaluate the leaching behavior of toxic metals during the use of fly ash in materials. Considering the fly ash utilization combination in conjunction with materials, the present investigation aims at proposing a frame work for analysis and assessment of behavior of fly ash – materials mixtures.

The present research study focuses on the characterization of coal, fly ash and fly ash materials (bricks, blocks and cement) by advance instruments technique, waste disposal system, physicochemical characterization and assessment of heavy metals in ash pond, utilization of fly ash and leaching of toxic metals during the use of fly ash in materials. Finally, the effectiveness of utilization of fly ash in the materials with leaching of toxic metals heavy was evaluated using different environmental condition. The present work related to analysis and evaluation on leaching of toxic metals during the use of fly ash in materials. These observations help us to understand the general effects of utilization of the fly ash in materials. Analysis and assessment of behavior of the fly ash and fly ash materials should lead to a sort of generalization based on which field engineers can effectively use and exploit the use of fly ash in construction of materials. Therefore, the mechanisms approach to analyze and assess the leaching behaviour of toxic metals during the use of fly ash in materials.

This study involved the characterization of the coal, fly ash and fly ash materials (bricks, blocks and cements) were studied systematically by X-ray diffraction (XRD), scanning electron microscopy-energy dispersive X-ray (SEM-EDX), X-ray fluorescence spectroscopy (XRF), Particle size distribution and Fourier Transform Infrared spectroscopy (FTIR). The fly ash effluents samples collected from the ash pond at Gandhinagar thermal power plants were analyzed and investigated for physico-chemical characteristics and the presence of heavy metals. The concentration of specific metals Fe, Cr, Cu, Ni, Cd, As, Zn and Pb in the fly ash effluents sample at ash pond were determined using ICP-MS. The primary objective of the research was to determine the leachability of toxic metals during the use of fly ash in materials. In the present study, laboratory leaching experiment have been conducted in the laboratory to determine the potential leaching of trace elements like Fe, Cr, Cu, Ni, Cd and Pb, from fly ash and fly ash materials (bricks, blocs and cements) samples under different leaching condition. For this, the fly ash samples from the Gandhinagar thermal power station and fly ash materials (bricks, blocks and cement) from the manufacturing places where used fly ash of Gandhinagar thermal power station were preparation of the different ratio (1:5, 1:10 and 1:20) of fly ash and fly ash materials with different leachants solution (acidic, neutral and alkaline) was done. The selected leaching tests, sequential batch leaching test (SBLT) and long-term leaching test (LTLT) were applied for fly ash and fly ash materials (bricks, blocks and cement) and the leaching of heavy metals was evaluated under different environmental conditions such as different pH (acidic, neutral and alkaline medium), different solid liquid ratio and time through leaching studies. These leaching tests were termed as pH, solid-liquid ratio and time dependent release tests.

The leachates obtained were analyzed for the selected trace elements. The concentrations of six specific metals Fe, Cr, Cu, Ni, Cd and Pb in the leachate were determined using ICP-MS. The leachates results indicate that there is no regular pattern of leaching of trace elements. The metal concentrations were plotted against time to observe the leaching trends in sequential batch leaching and long-term leaching tests.

The material used in this study was coal and fly ash collected from Gandhinagar thermal power plant, and fly ash materials (bricks, blocks and cements) collected from the manufacturing site, nearby location of Gandhinagar town, which used the fly ash of Gandhinagar thermal power plants and was tested for leaching of toxic metals. The material was characterized by using a number of analytical techniques such as XRD, SEM-EDX, XRF and FTIR analysis. XRD patterns of the coal and fly ash sample show mainly present of quartz whereas bricks, blocks and cements show mainly berlinite, tobermorite and calcium silicate respectively. XRD analysis has shown that maximum % of the fly ash is in the amorphous glass phase, and that the main crystalline phases are mullite and quartz. XRD analysis revealed that FA particles mostly consist of Silica and alumina with less percentage of Fe_2O_3, Cao and others. The chemical composition of fly ash as determined by XRF analysis has confirmed that this is a Class F fly ash, with low CaO content. XRF measurements showed that the amount of silica in coal, fly ash, fly ash bricks and blocks was higher in comparison to fly ash cements. Higher amount of CaO was observed in fly ash cements whereas CaO was low in fly ash. Based on the results of XRD and XRF analyses, more than half of the fly ash composition constituted of silica, non- opaque spherical particles, and complete opaque spheres, mostly aluminum and iron oxide compounds. From the compositions of fly ash sample, it can be concluded that the fly ash sample belongs to ASTM class F. As the fly ash belongs to Class F category which acts as pozzolanic in nature, so it needs alkaline substance for becoming the strengthening. Pozzolanic properties of fly ash can be identified by presence/absence of calcium oxide. So class F fly ash is the weak in pozzolanic as very less amount of calcium oxide present. SEM images revealed the amorphous nature of the fly ash and distinct difference in the morphology of the samples. The spherical morphology and small particle size of the fly ash may enhance its applicability as filler in polymers. The EDX spectra showed the percentage distribution of the three principal elements, O, Si and Al, in the fly ash samples. Visual observations of the SEM images show a distinct spherical nature for the grains for the fly ash samples. SEM analysis revealed the morphology of FA particles that are mostly spherical in shape. FTIR measurements indicated that coal, fly ash, fly ash bricks (FAB), blocks (AAC) and cements (FAC) showed shifts in frequencies of major bands and also modification of their intensities.It was also found that the measurement of particle size distribution and amorphous content is sufficient to assess the strength potential of fly ash utilization in materials.

The effect of seasonal variations on effluents water quality of ash pond at Gandhinagar thermal power plant was studied. The summer, monsoon and winter seasons showed different level of seasonal fluctuations in various physicochemical parameters. Fly ash effluents at ash pond for summer, winter and monsoon season during 2015-2016 were within the maximum permissible limit prescribed by IS 22096. The fly ash effluent in terms of the elemental concentrations investigated did not seem to be so potential in polluting the environment. This studies has establish that some physico-chemical parameters like temperature, pH, conductivity, total dissolved solid, alkalinity and other parameters was within the permissible limits of IS 22096. The heavy metal levels were also within the permissible limit prescribed by IS 22096 in all effluents samples. Regulation estimation of the above mentioned parameter would be helpful to improve ash pond quality. From the experimental results it was found that at lower pH, the concentrations of leaching metal ion were high. As the pH values go on increasing, the leaching order also changes in the decreasing way. The effluent water around the area away from the disposal pipe was found to be alkaine in nature. The order of heavy metals are found as Fe > Cu > Zn > Pb > Ni >Cr> As > Cd. The heavy metal concentration was observed maximum in summer season into ash pond. The heavy metals in fly ash leachates are very important in view of environmental pollution have the seasonal variation in the following order: Summer season > Winter season > Monsoon season. From the experimental results, it was also found that pH, Cl-, alkalinity, SO_4^{2-}, NO_3^- etc. have very important influence over the distribution of different forms of metals and seasonal variation of these heavy metals. From the above details it can be said that the ash pond leachates through leaching processes, affect the ground water to a large extent. The leachates therefore have a definite pollution potential for the ground water bodies.

The leaching of heavy metals from the ash pond mainly depends on the pH. The release of heavy metals from the ash slurry increases with the decrease in pH. The pH decrease in the ash pond is caused by SO_2 which can be adsorbed on the surface of the fly ash or reach through the atmosphere. It has been already found that rainwater has an acidic pH of up to 5.5 and dissolved atmospheric SO_2 in the vicinity of the thermal power plant further reduces the pH. This causes the more acidic conditions to become ash ponds and increases the release of heavy metals from the ash slurry into the groundwater.

In view of the overall results obtained for heavy metals contents of the fly ash effluents sample from the ash pond at thermal power plants, effluent did not seem to pose any serious threat to the environment. In general, after summarizing all the facts, which have resulted from this investigation, we could say that the fly ash effluents contains moderate amounts of heavy metals and their effects on ground water, soil health and uptake by plants are probably insignificant.

The elements (Fe, Cr, Cu, Zn, Cd, Ni, As and Pb) gave concentrations within the permissible limits as per IS 2296 norms during the winter, summer and monsoon season.

The detailed experimental study that has been taken up on fly ash and fly ash materials (FAB, AAC and FAC) leads to some important observations. This observation indicates that a basic frame work can be developed for analyzing the behavior of fly ash materials. The fly ash and fly ash materials (FAB, AAC and FAC) was tested for the leaching of heavy metals, viz., Fe, Cr, Cd, Cu, Pb, and Ni. The conditions under which the metals are leached from these samples were influenced by different experimental test, condition and the results are summarized below:

The leaching of fly ash and fly ash materials (bricks blocks and cements) in different leachant medium (acidic, neutral and alkaline) and different solid-liquid ratio (1:5, 1:10 and 1:20) have a different amount of toxic elements. The effect of pH on leaching is generally dominant, because pH has a major influence on solubility of most chemical species. Among the trace elements originally present in fly ash, Pb and Cd are produced, at much lower concentrations in the leachates obtained during the different intervals. The other elements such as Fe, Ni, Cu and Cr were detectable in the percolate show their presence. The chemistry of the leachate varies considerably, with a pH ranging from acidic to alkaline. Most of the fly ash leachate tends to be alkaline due to the presence of lime, while fly ash with a high Fe content can lead to an acidic leachate through oxidation and release of hydrogen ions. The pH value of leachates obtained during leaching process seems to be related to the alkalinity of the fly ashes and also to the fly ash materials (bricks blocks and cements). The duration of leaching in affects the leachability of the toxic elements in fly ash and fly ash materials (blocks of bricks and cements).

Widely varying leachability of heavy metals have been observed in the experiments covering strongly acidic medium to alkaline medium in both sequential batch leaching and long-term leaching modes. It is found that in the acidic medium (pH 4.00), the concentrations of Fe, Cr, Cd, Cu, Ni and Pb in the leachate of samples were substantial in all the four 7 days cycle. It was found that concentration of Fe in all experiments where solid - liquid ratio 1:5, were found to be cross the permissible limit prescribed by IS 22096. The concentrations of other toxic metals (except Fe) were found to be within permissible limit prescribed by IS 22096. The concentration of toxic metals in the leachate of all samples were substantial in all 7 days extraction cycles and even in all leaching medium, varying from acidic to alkaline region. Elements such as Fe are enriched in fly ash, fly ash materials and in an acidic medium, their leaching behavior was more interestingly. Elements such as Pb, Cu and Cr showed moderate leaching while Cd exhibited subdued leaching.

In long-term leaching test with different leachant medium (acidic, neutral and alkaline), concentrations of Fe, Cr, Cd, Cu, and Ni increase with contact time up to 180 days, whereas concentrations of Pb decrease under experimental conditions. It was seen for a long-term leaching test that the concentrations of toxic metals (except iron) in the leachate increase with increasing solid–liquid ratio. The results indicate that considerable release of toxic heavy metals would occur particularly under acidic leaching conditions. Since the mobility of toxic metals from fly ash and fly materials was negligible (except solid-liquid ratio 1:5).

The leachability of toxic metals shows the trend as Acidic > Alkaline > Neutral. The leachability of Pb and Cd fluctuates over time. It was observed that leachability does not reach stability in the leaching process with Pb in any of the leachant medium. The leachability of Cd was found on higher side when the fly ash is mixed with the extraction solution.

Conclusions

On the basis of the study of leachability of toxic metals during the use of fly ash in materials, the following conclusions can be drawn:

- The nature of fly ash and fly ash materials (bricks, blocks and cement) was amorphous and the highest concentrations of the SiO_2 were present in coal, fly ash, fly ash bricks and blocks materials whereas CaO was more in fly ash cement.
- The concentrations of all the toxic metals in the ash pond during winter, summer and monsoon season were within the permissible limits for discharge of effluents as per Indian Standards.
- The trends of trace elements during the winter, summer and monsoon seasons was as Fe > Cu > Zn > Pb > Ni > Cr > As > Cd.
- The heavy metals in fly ash leachates are very important in view of environmental pollution have the seasonal variation in the following order: Summer season > Winter season > Monsoon season

- Leaching of toxic metals from fly ash and fly ash materials (FAB, AAC and FAC) were influenced by parameters, such as pH effect, solid-liquid ratio, contact time and agitation speed.
- The results confirmed that, acidic medium more influences the release rate of toxic metals.
- The amount of Cr leached out of maximum in fly ash cement in comparison to fly ash, fly ash bricks and blocks.
- The leaching capacity in all cases showed decreases with increases in contact time.
- Generally, percent leaching increased with increasing soli-liquid ratio, contact time and agitation speed.
- The sequential batch leaching tests results showed similar trends as in long- term leaching tests. The result showed that leaching capacity were high in acidic medium and followed by alkaline and neutral medium and also leaching capacity were maximum in high solid – liquid ratio of 1:5 and followed by solid – liquid ratio of 1:10 and 1:20.
- Widely varying leachability of heavy metals have been observed in the experiments covering strongly acidic to basic pH of water in both sequential batch leaching and long-term leaching modes.
- The leachability of toxic metals shows the trend as Acidic > Alkaline > Neutral
- The concentrations of toxic metals tested were found to be greater in all extraction cycles with lower final pH than in the higher one.
- In long-term leaching test, concentrations of Fe, Cu, Cr, Ni and Cd increase with contact time up to 180 days, whereas concentrations Pb decrease under experimental conditions.
- It was seen for a long-term leaching test that the concentrations of tested toxic metals in the leachate increase with increasing solid–liquid ratio.

Suggestions for further work

The following works may be carried out in future:

- Using the most favorable conditions as obtained from the leaching tests is to be undertaken for evaluating the practical utility of the fly ash materials for leaching process in industrial scale.
- The nanostructured fly ash may be studied for adsorption properties.
- To evaluate different mathematical models to understand the leaching process more clearly.
- To study desorption of the toxic metals from the fly ash materials and hence to suggest suitable methods for utilization of fly ash in materials.
- To study strength of the fly ash materials can be further increased by adding the necessary additives in a higher percentage amount & providing them enough curing period for better compaction. For which those composites can meet the requirements for construction purposes.