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Leaching Characteristics of Selected Elements from Indian Coal Ash

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Abstract: Long-term leaching experiments have been conducted to determine release of different ions and heavy metals from different coal ashes obtained from Ramagundam Super Thermal Power Plant, Andhra Pradesh and Chandrapura Thermal Power Plant, Jharkhand. Four columns of Ramagundam fly ash, bottom ash, pond ash, and weathered ash and three columns of Chandrapura bottom ash, pond ash, and weathered ash have been prepared. Leaching experiment has been conducted for one year. The leachates obtained have been monitored for levels of dissolved constituents and heavy metals. Results for leachates indicate that initially maximum concentrations of dissolved inorganic constituents, who have been admixed, with the surface of fly ash particles have been leached out. Irregular pattern of heavy metals released have been obtained in leachates. The leaching behaviour indicated slow and long-term leaching of heavy metals, which have been associated with the ash particles.

Key words: Fly ash, long-term leaching, heavy metal.

Introduction

Currently 20% of the total fly ash, produced in India, is utilized for different industries, and the remainder is disposed as waste in ash disposal ponds. One of the major difficulties in disposing off such huge quantity of coal ash is the possible leaching out of pollutants into surface and ground water. Different workers (Prasad et al., 1996; Prasad and Jaiprakas, 2000; Prasad et al., 2004; Gregory and Roy, 1985; Wadge and Hutton, 1987; Querol et al., 2001; Theis and Gardner, 1990; Liem et al., 1983; Wasay, 1992; Fleming et al., 1996) have studied the environmental pollution due to leaching of different pollutants specially heavy metals from disposed fly ash. Leaching of non-metals like As, Se, and B from disposed fly ash has also been found potentially harmful to both vegetation and animals (Vander et al., 1996; Vander and Comans 1994; Cox et al., 1978).

Although a number of short-term leaching, extraction and equilibration studies have demonstrated many of the initial leaching characteristics of fly ash, the long-term leaching behaviour and ion release properties must be clarified before disposal or utilization of fly ash. Results obtained in short-term leaching experiments may not accurately represent the long-term leaching behaviour and concomitant environmental hazards or benefits of fly ash. Accordingly in the present paper study has been carried out to evaluate the leaching behaviour or aqueous dissolution of fly ash under prolonged leaching conditions.

Methodology

Fly ash, bottom ash, pond ash and weathered ash have been obtained from Ramagundam Super Thermal Power Plant, Andhra Pradesh and Chandrapura Thermal Power Plant, Jharkhand. In both the power plants bituminous coal is being used for power generation. For the leaching experiment, seven experimental open columns have been used. Each column of 100 cm. long with 7.5 cm. internal

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diameters has been used. One kilogram of each fly ash, bottom ash, pond ash and weathered ash of Ramagundam and bottom ash, pond ash and weathered ash of Chandrapura have been packed in seven separate columns respectively, to ensure a homogeneous matrix and to avoid blockage or development of preferential routes during flow of water through them. The columns with both ends open have been used in the experiment; however at the other end small hole type opening have been made to collect leachates. From the determined value for particle density and the measured volume and amount of ash, each columns pore volume has been determined. Half pore volume of distilled water has been passed through each column every day. 2.5 times pore volume of water has been passed every week and 10 pore volume of water has been passed through each column every month. Columns have been continuously leached over a period of one year at a flow rate governed by the hydraulic conductivity of the coal ash cores. Collected leachate samples have been monitored for pH, total dissolved solids, total hardness, Ca, Mg, Cl, F, SO_4, K, and heavy metals like Cu, Cd, Zn, Pb, Fe, Cr, Mn and Ni. The analysis was carried out by different standard procedures (Table 1).

Table 1: Analytical method for different parameters

Species	*Method*
pH	Orion specific ion meter
TDS	Evaporation technique
TH	EDTA titrametric
Ca	EDTA titrametric
Mg	By calculation
Cl	Argentometric titration
SO_4	Gravimetric analysis
F	Orion specific ion meter
K	Orion specific ion meter
Cu	Atomic Absorption Spectrophotometer
Cd	——Do——
Cr	——Do——
Fe	——Do——
Pb	——Do——
Zn	——Do——
Mn	——Do——
Ni	——Do——

Results and Discussions

The changes in chemical characteristics of different leachate samples collected periodically during the one year leaching experiment have been studied. Initial characteristics of leachates obtained from first few pore volumes of water showed alkaline pH, maximum concentrations of dissolved solids, total hardness, calcium, sulphate, fluoride and potassium. With leaching, pH values decreased in somewhat stepwise fashion (Figure 1). After passing few pore volumes of water through the columns sharp decline in concentrations of dissolved solids, total hardness, Ca, SO_4, F, and K have been observed. A number of heavy metals like Cu, Zn, Cd, Cr, Pb, Fe, Ni and Mn showed irregular pattern of leaching behaviour.

Column Leaching of Fly Ash of Ramagundam

The experiment conducted on Ramagundam fly ash revealed that the concentration of different parameters such as total dissolved solids, total hardness, Ca, Mg, K, Cl, SO_4 and F analysed in leachates has been found to be higher initially which reduced gradually. It is evident from Figure 2 that substantial decrease in the concentration of all parameters has been observed, after passing about 15-pore volume of water. The experiment was conducted up to 76-pore volume of water passed through the fly ash column. Further water could not be passed due to hard mass formation of fly ash in the column. After passing first pore volume of water, the concentration of different parameters like total dissolved solids, total hardness, Ca, Mg, K, Cl, SO_4 and F have been 927, 700,

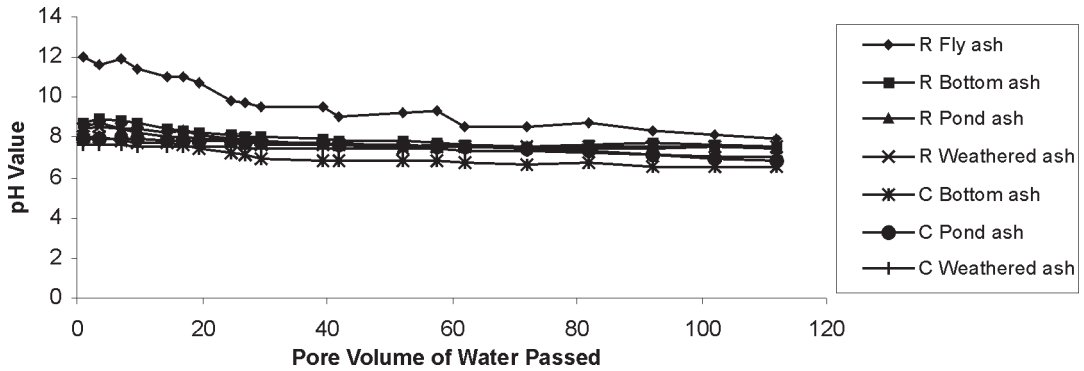

Figure 1: Change in pH in column leaching.

264, 9.72, 786, 180, 8.24 and 0.407 mg/l, respectively. After passing 76-pore volume of water, the concentrations decreased to 102, 76, 20.8, 5.8, 2.0, 8.0, 13.5, and 0.16 mg/l, respectively.

Heavy metals analysis has been carried out for each samples collected after 10-pore volume of water passed through the fly ash column. It is worthwhile to note that except chromium, other heavy metals released in low concentration. The concentration of chromium (0.8692 mg/l) has been found to be higher in comparison to the value (0.05 mg/l) prescribed limit for drinking water specification. Maximum concentration of 0.0159, 0.0765, 0.0755, 0.0116, 0.005, 0.0152, and 0.0319 mg/l, respectively for Cu, Zn, Fe, Mn, Cd, Pb, and Ni have been observed in collected leachate at different pore volume of water passed through the column (Figure 3).

Column Leaching of Bottom Ash of Ramagundam

Like fly ash, the experiment conducted on Ramagundam bottom ash revealed that the concentration of different parameters such as total dissolved solids, total hardness, Ca, Mg, K, Cl, SO_4 and F analysed in leachates has been found to be higher initially which reduced gradually. It is evident from Figure 4 that there has been substantial

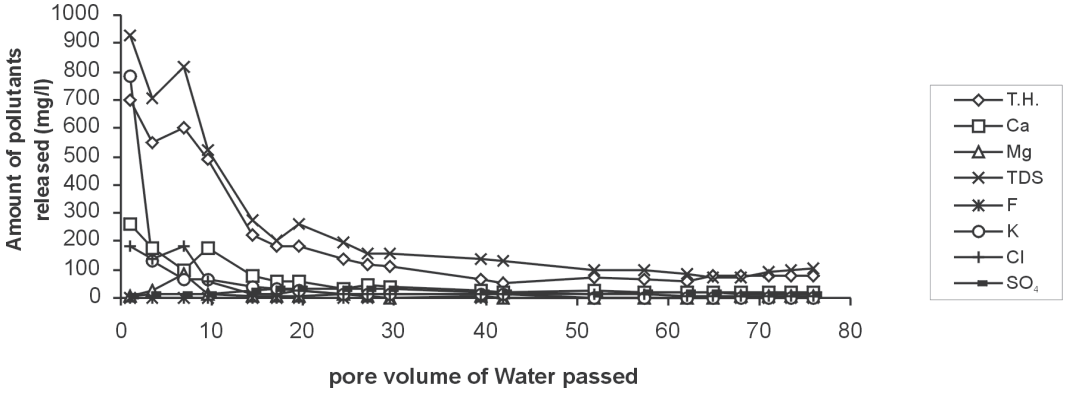

Figure 2: Column Leaching Experiment of Ramagundam fly ash.

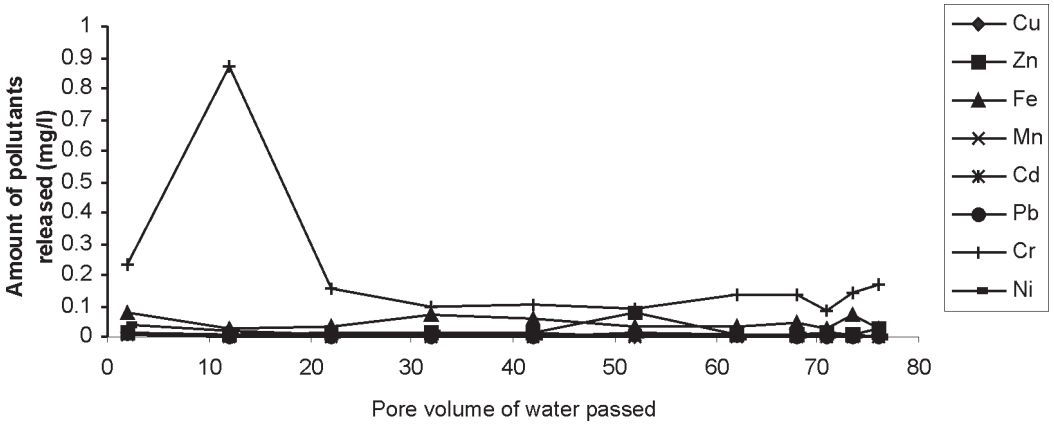

Figure 3: Heavy metals released through column leaching of Ramagundam fly ash.

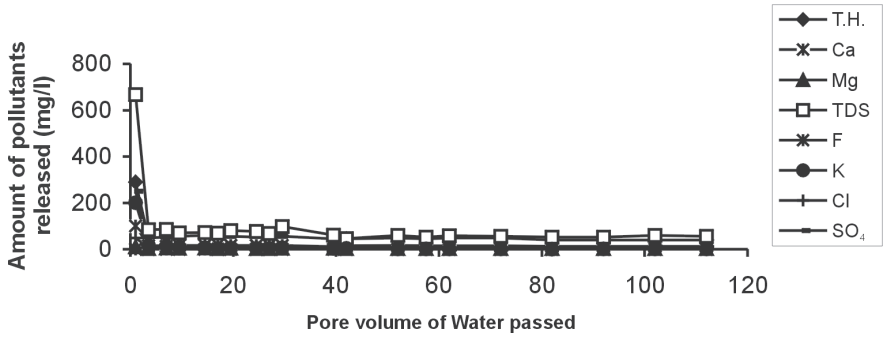

Figure 4 Column leaching experiment of Ramagundam bottom ash.

decrease in the concentration of all parameters after passing about 3.5-pore volume of water. The experiment has been conducted up to 112-pore volume of water passed through the bottom ash column. After passing first pore volume of water, the concentration of different parameters like total dissolved solids, total hardness, Ca, Mg, K, Cl, SO_4 and F have been 667.5, 290, 100, 9.72, 250, 201, 48, and 0.511 mg/l, respectively. After passing 112-pore volume of water through the column, the concentrations decreased to 56, 40, 12.8, 1.94, 8.0, 1.1, 4.0 and 0.03 mg/l, respectively.

Heavy metals analysis carried out, each after passing 10-pore volume of water through the column revealed that lower concentrations (less than 0.09 mg/l) of heavy metals like Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni have been released in the leachates. The concentrations of all heavy metals have been varying considerably in each analysis (Figure 5).

Maximum concentration of 0.0088, 0.037, 0.0854, 0.0065, 0.0014, 0.0337, 0.0141, and 0.0078 mg/l, respectively for Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni has been observed in collected leachate at different pore volume of water passed through the column. None of the heavy metals has crossed the prescribed standard limit of drinking water specification (IS: 10500).

Column Leaching of Pond Ash of Ramagundam

Like fly ash and bottom ash, the experiment conducted on Ramagundam pond ash revealed that the concentration of different parameters such as total dissolved solids, total hardness, Ca, Mg, K, Cl, SO_4 and F analysed in leachates has been found to be higher initially which reduced gradually. It is evident from Figure 6 that substantial decrease in the concentration of all parameters after passing about 3.5-pore volume of water has been observed. The experiment has been conducted up to 112-pore volume of water passed through the bottom ash column.

After passing first pore volume of water through the column the concentrations of total dissolved solids, total hardness, Ca, Mg, SO_4, K, Cl and F have been 763, 530, 168, 26.7, 650, 403, 148, and 0.457 mg/l respectively. After passing 112 pore volume of water through the column the concentrations have been decreased to 55, 32, 8.0, 3.0, 9.0, 1.5, 4.0 and 0.045 mg/l, respectively. Heavy metals analysis in collected leachates through pond ash column, after every 10-pore volume of water through the column, revealed that lower concentrations (less than 0.09 mg/l) of heavy metals like Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni have been released in the leachates. The concentrations of all heavy metals have been varying considerably in each analysis (Figure 7).

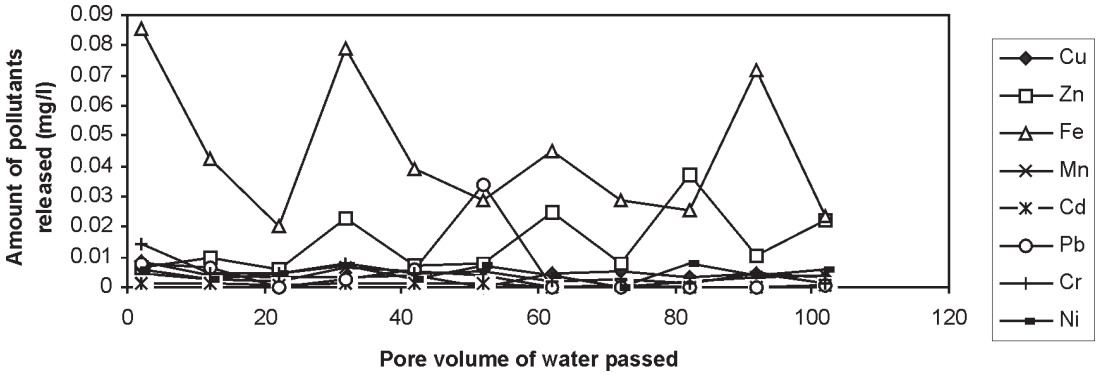

Figure 5: Heavy metals released through column leaching of Ramagundam bottom ash.

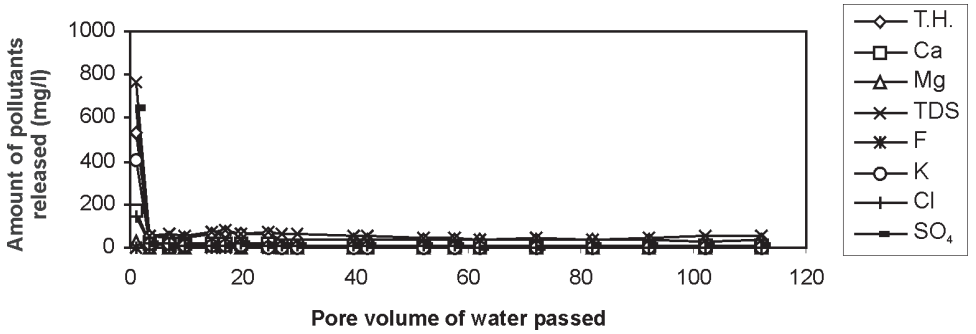

Figure 6: Column leaching experiment of Ramagundam pond ash (with distilled water).

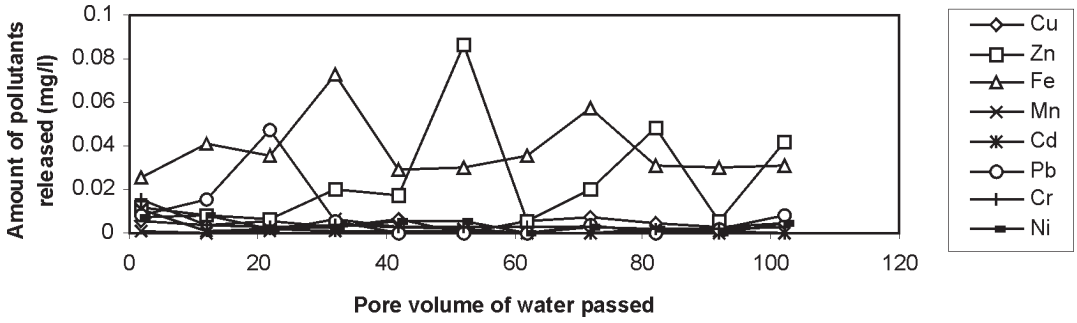

Figure 7: Heavy metals released through column leaching of Ramagundam pond ash.

Maximum concentration of 0.0071, 0.0862, 0.0727, 0.0061, 0.001, 0.0473, 0.0152, and 0.0078 mg/l, respectively for Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni has been observed in collected leachate at different pore volume of water passed through the column. None of the heavy metals has crossed the prescribed standard limit of drinking water specification (IS: 10500).

Column Leaching of Weathered Ash of Ramagundam

The long-term leaching experiment conducted on weathered ash of Ramagundam, revealed that as compared to fly ash, bottom ash and pond ash, very less concentrations of ions in the leachate have been obtained after first pore volume of water passed through the column. It has been due to long-term exposure of ash in the open environment. After passing first pore volume of water through the column, the concentrations of total dissolved solids, total hardness, Ca, Mg, SO_4, K, Cl and F have been 225, 110, 40, 2.43, 71.7, 33.4, 20.0 and 0.275 mg/l, respectively. After passing 112-pore volume of water through the weathered ash column, the concentrations have been decreased to 55.0, 44.0, 12.8, 2.9, 3.5, 1.15, 4.0 and 0.034 mg/l, respectively (Figure 8).

Heavy metals analysis in the collected leachates through weathered ash column, after every 10-pore volume of water through the column, revealed that lower concentrations of heavy metals (less than 0.052 mg/l) like Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni have been released in the leachates. The concentrations of all heavy metals have been varying in the collected leachates at different pore volume of water passed through the column (Figure 9). Maximum concentration of 0.0087, 0.0121, 0.0516, 0.0155, 0.0018, 0.0098, 0.0058, and 0.0172 mg/l,

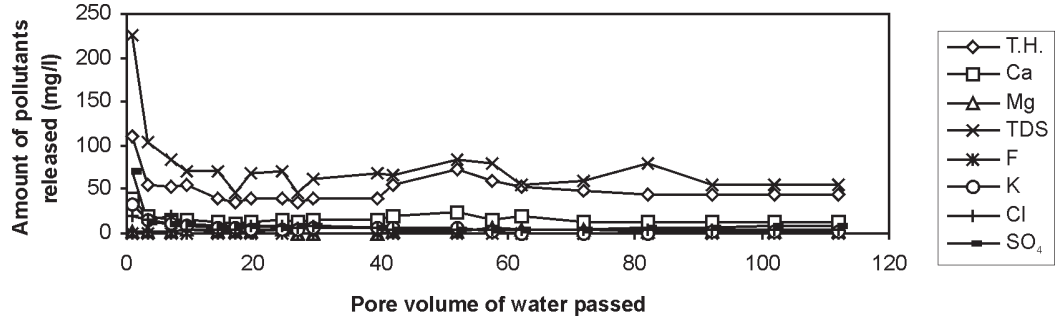

Figure 8: Column leaching experiment of Ramagundam weathered ash.

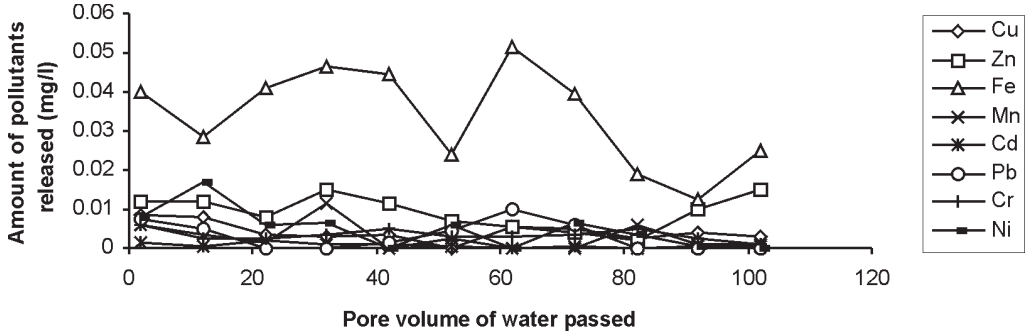

Figure 9: Heavy metals released through column leaching of Ramagundam weathered ash.

respectively, for Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni has been observed in collected leachate at different pore volume of water passed through the column. None of the heavy metals concentration crossed the prescribed standard limit of drinking water specification (IS: 10500).

Column Leaching of Bottom Ash of Chandrapura

Long-term leaching experiment conducted on Chandrapura bottom ash column, revealed that in the beginning higher concentrations of ions have been released but just after passing 3.5-pore volume of water through the column, there has been substantial decrease in the concentration of ions (Figure 10).

After passing first pore volume of water through the bottom ash column, the concentrations of total dissolved solids, total hardness, Ca, Mg, SO_4, K, Cl and F have been 177, 60.0, 19.2, 2.91, 47.5, 90.8, 16.0 and 1.53 mg/l, respectively. After passing 112-pore volume of water through the bottom ash column, the concentrations have been decreased to 38.0, 16.0, 4.0, 1.45, 9.0, 1.2, 4.0 and 0.033 mg/l, respectively.

Heavy metals analysis has been carried out for each sample collected after 10-pore volume of water passed through the bottom ash column. It is worthwhile to note that heavy metals such as Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni have been released in low concentration (less than 0.07 mg/l). The concentrations of all heavy metals have been varying in the collected leachates at different pore volume of water passed through the column (Figure 11).

Maximum concentration of 0.06715, 0.0172, 0.0309, 0.00495, 0.0011, 0.0143, 0.0057, and 0.0232, mg/l, respectively, for Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni has been observed in collected leachate at different pore volume of water passed through the column. The concentration of Cu exceeded twice the prescribed standard limit of drinking water (0.05 mg/l) during the investigation process. None of the other heavy metals have shown higher value than the prescribed limit of drinking water (IS: 10500).

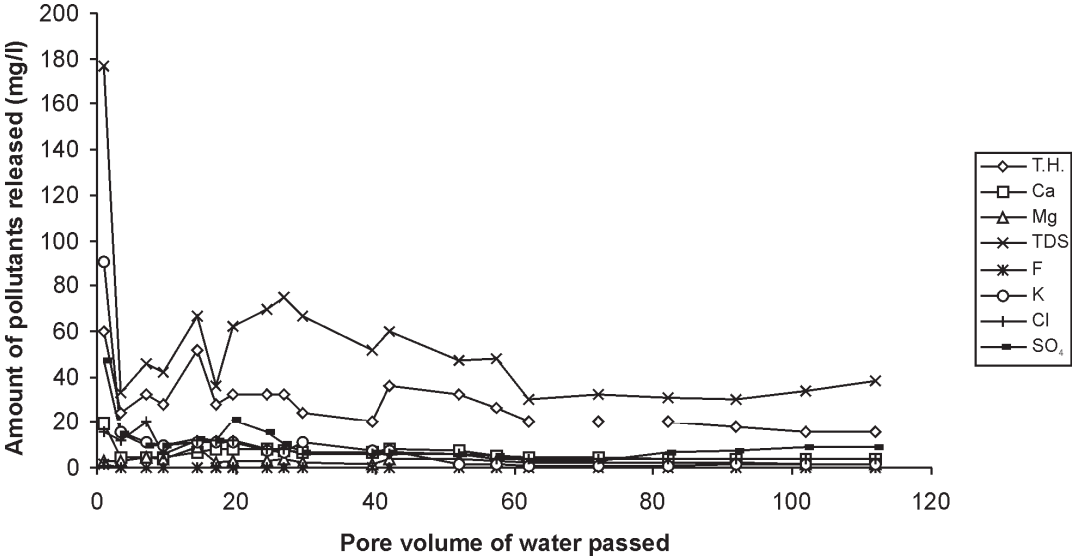

Figure 10: Column leaching experiment of Chandrapura bottom ash.

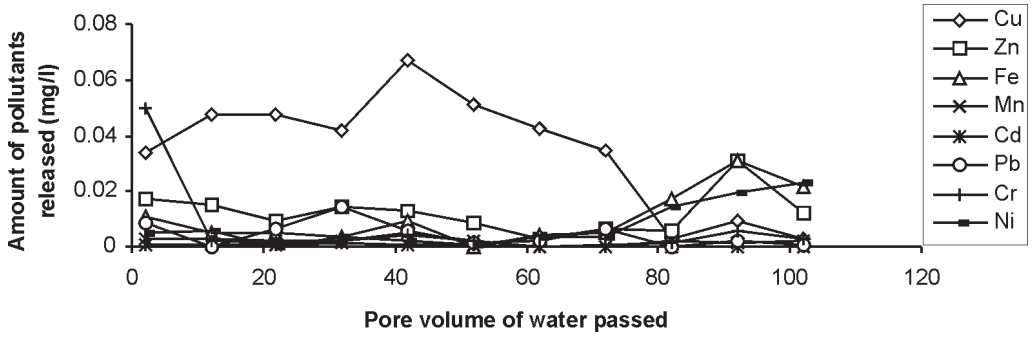

Figure 11: Heavy metals released through column leaching of Chandrapura bottom ash.

Column Leaching of Pond Ash of Chandrapura

Like bottom ash, the experiment conducted on Chandrapura pond ash revealed that the concentration of different parameters such as total dissolved solids, total hardness, Ca, Mg, K, Cl, SO_4 and F analysed in leachates has been found to be higher initially which reduced gradually. It is evident from Figure 12 that substantial decrease in the concentration of all parameters, after passing about 3.5-pore volume of water, has been observed. The experiment has been conducted up to 112-pore volume of water passed through the bottom ash column. After passing first pore volume of water, the concentration of different parameters like total dissolved solids, total hardness, Ca, Mg, SO_4, K, Cl, and F have been 386, 190, 33.6, 25.75, 82.4, 96, 12.0 and 12.5 mg/l, respectively. After passing 112-pore volume of water through the pond ash column, the concentrations have been decreased to 41.0, 28.0, 7.2, 2.43, 4.0, 1.25, 4.0 and 0.089 mg/l, respectively.

Heavy metals analysis has been carried out for each sample collected after 10-pore volume of water passed through the bottom ash column. It has been observed that heavy metals such as Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni have been released in low concentration. The concentrations of all heavy metals have been varying in the collected leachates at different pore volume of water passed through the column (Figure 13).

At two occasions, concentrations of copper has exceeded its prescribed limit in drinking water specification (0.05 mg/l). Otherwise all other heavy metals have shown lower concentrations than their prescribed limit in drinking water specification (IS: 10500). The maximum concentrations of heavy metals that have been leached out through the pond ash column have been 0.09175, 0.0224, 0.0373, 0.00695, 0.00155, 0.060, 0.0045 and 0.0142 mg/l, respectively for Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni. Except Cu at two analyses, none of the heavy metals have crossed the prescribed standard limit of drinking water specification (IS: 10500).

Column Leaching of Weathered Ash of Chandrapura

Weathered ash of Chandrapura was six months old. The long-term leaching experiment conducted on weathered ash column of Chandrapura, revealed that in the beginning of the experiment, higher concentration of ions (but less than fresh pond ash) have been released in the leachate and afterwards a gradual decrease in the concentration of all ions have been observed, as more and more pore volume of water has been passed through

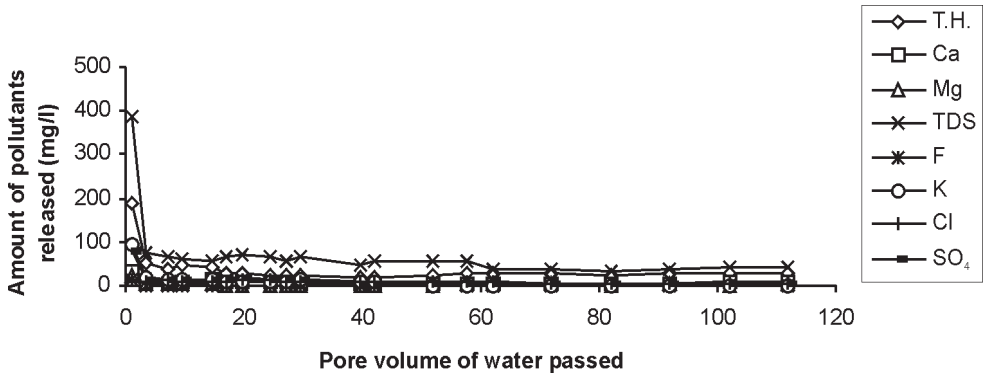

Figure 12: Column leaching experiment of Chandrapura pond ash.

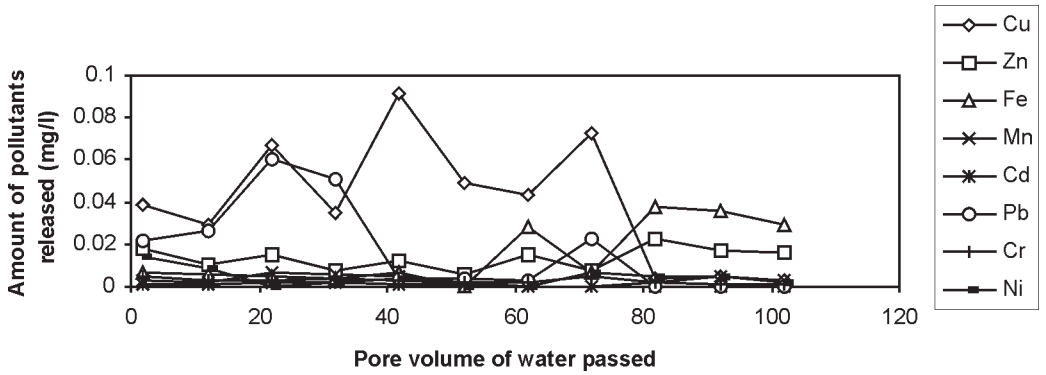

Figure 13: Heavy metals released through column leaching of Chandrapura pond ash.

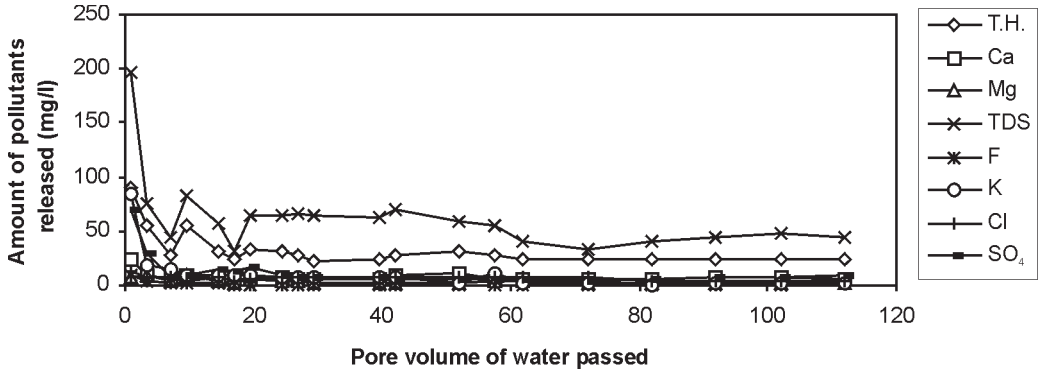

Figure 14: Column leaching experiment of Chandrapura weathered ash.

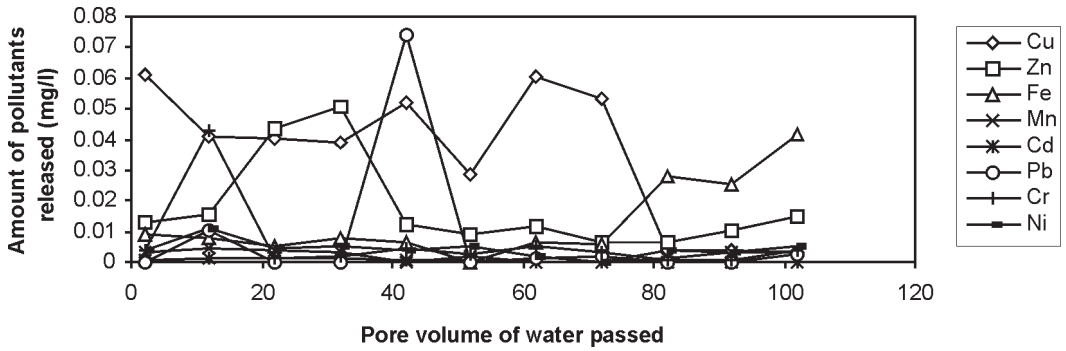

Figure 15: Heavy metals released through column leaching experiment of Chandrapura weathered ash.

the column (Figure 14). After passing first pore volume of water, the concentration of different parameters like total dissolved solids, total hardness, Ca, Mg, SO_4, K, Cl and F have been 197, 90, 24, 7.29, 70.04, 83.8, 12 and 9.23 mg/l, respectively. After passing 112-pore volume of water through the column, the concentrations have been decreased to 45.0, 24.0, 6.4, 1.94, 8.3, 1.5, 4.0 and 0.099 mg/l, respectively. Heavy metals analysis has been carried out for each sample collected after 10-pore volume of water passed through the bottom ash column. It has been observed that heavy metals such as Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni have been released in low concentration (less than 0.075 mg/l). The concentrations of all heavy metals have been varying in the collected leachates at different pore volume of water passed through the column (Figure 15).

The maximum concentration of heavy metals released in the leachates have been 0.0608, 0.0507, 0.0416, 0.00435, 0.00135, 0.0741, 0.043 and 0.011 mg/l, respectively for Cu, Zn, Fe, Mn, Cd, Pb, Cr, and Ni. At few occasions the concentration of copper has been found more than 0.05 mg/l in the leachate. Rest none of heavy metals showed higher level of concentration, than their prescribed standard limit in drinking water specification (IS: 10500).

Conclusion

Open column leaching experiment carried out on fly ash, bottom ash, pond ash, and weathered ash of Ramagundam and bottom ash, pond ash, and weathered ash of Chandrapura showed that in all experiment, in the beginning higher concentrations of total dissolved solids, total hardness, Ca, Mg, Cl, SO_4, F and K have been released but gradually after passing few pore volume of water through the column, substantial decrease in the concentrations of all parameters have been observed.

The pH values of leachates obtained during leaching process appear to be related to the alkalinity of the original ashes. Initially Ramagundam fly ash produced alkaline leachate with pH values more than 12. Rest other ashes initially produced neutral to alkaline leachate with pH 7.5 to 8.5.

The release of heavy metals from all the ash columns was slow and some times complex process, strongly dependent on the pH developed during interaction with the leaching solution used. Equilibrium between solid ash phase and solution was not reached during any of the leaching experiments.

The highest Cr concentrations observed in leaching solution obtained from Ramagundam fly ash column at

an initial pH of more than 11.00. Release of heavy metals from ash columns depends not only on the element concentration and mode of occurrence, but also on the chemical conditions associated with the leaching process.

References

Cox, J.A., Lundquist, G.L., Przyjazny, A. and C.D. Schmulbach (1978). Leaching of boron from coal ash. *Environmental Science and Technology,* **12:** 722-723.

Fleming, L.N., Abinteh, H.N. and H.I. Inyang (1996). Leachant pH effects on the leachability of metals from fly ash. *Journal of Soil Contamination*, **5(1):** 53-59.

Gregory, R.M. and F. Roy (1985). Trace elements concentration as a function of particle size in fly ash from a pulverized coal utility boiler. *Envi. Science. Technology*, **19(9):** 796-803.

Liem, H., Sandstrom, M., Wallin, T., Carne, A., Rydevik, U., Thurenius, B. and P. Moberg (1983). Studies on the Leaching and Weathering Processes of Coal ashes. *Water Science Technology*, **15:** 163-191.

Prasad, B., Benerjee, N.N. and B.B. Dhar (1996). Environmental Assessment of Coal Ash Disposal: A review. *Journal of Scientific & Industrial Research*, **55:** 772-780.

Prasad, B. and K.C. Jaiprakas (2000). Studies of Selected Coal Fly Ash leachates for Environmentally Safe Disposal. *Indian J. Environ. Prot*., **20(4):** 275-279.

Prasad, B., Mondal, K.K. and A. Gupta (2004). Impact on water Environment due to Leaching of Heavy metals from Indian fly ash. Proceedings of International Seminar on Mineral Processing Technology 2004, Regional Research Laboratory, Bhubaneswar.

Querol, X., Umana, J.C., Alastuey, A., Ayora, C., Lopez- Soler, A. and F. Plana (2001). Extraction of soluble major and trace elements from fly ash in open and closed leaching systems. *Fuel*, **80:** 801-813.

Theis, T.L. and K.H. Gardner (1990). Environmental Assessment of Ash Disposal. *Critical Reviews in Environmental Control*, **20(1):** 21-42.

Vander Hoek, E.E., Van Elteren, J.T. and R.N.J. Comans (1996). Determination of As, Sb and Se Speciation in fly ash leachates. *International Journal of Environmental Analytical Chemistry,* **63:** 67-79.

Vander Hoek, E.E. and R.N.J. Comans (1994). Speciation of As and Se during leaching of fly ash. *In:* Gaumans, J.J.J.M., Vander Sloot, H.A. and Aalbers, ThG. (Eds). Environmental aspects of Construction with Waste Materials. Elsevier Science, New York.

Wadge, A. and M. Hutton (1987). The Leachability and Chemical Speciation of Selected Trace elements in fly ash from Coal combustion and Refuse Incineration. *Environmental Pollution*, **48:** 85-99.

Wasay, S.A. (1992). Leaching behavior of trace toxic metals from fly ash, their seepage control to ground water and utilization of fly ash. *Journal of Environmental Science and Health,* **A27(1):** 25-39.

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