Leachate Potential of Fly Ash for Toxic Elements in and Around Ash Disposal Sites

Shivam Kapoor[1], Shweta Sharma[2] and Robin A. Christian[3]

[1]*M.Tech Scholar, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India*
[2]*M.Tech Scholar, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India*
[3]*Civil Engineering Department, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, India*

Abstract: The coal-fired thermal power plants produce enormous quantity of fly ash and a portion of that is ultimately dumped in the ash dykes in the form of slurry. Then, after settling, the effluent is taken back, as presently maintained, for recirculation through Ash Water Recirculation System (AWRS). This effluent and pond ash contain various metal ions out of which the ions of concern are Hg, Cr, As, Ni, Cd, Cu, Pb, Zn, and B which may percolate down & pollute ground water. Solubility of these elements is less. This study investigates the leachate potential of heavy metal for fly ash of Ramagundam Super Thermal Power Plant, Ramagundam. It also studies the impact of leaching of toxics from ash dumps to water bodies within an area falling in 10 Km radii of ash dumps. The results shows that 5-30% of toxic elements (As, Cu, Pb) are leachable and around 10% of total Cd was solubilized in the acidic pH range (3 to 5). This study observed that some heavy metals, trace elements and flouride in ground water and surface water are present in such quantity which is not desirable in drinking water for direct use as per WHO standards. Study concludes that fly ash has moderate polluting effect on ground water.

Keywords: Coal, Fly Ash, Leaching, Groundwater contamination.

1. INTRODUCTION

The term \`coal\` is believed to have originated from the Sanskrit world \`kaal\`, meaning black. In ancient time, coal was known as burning rock and was believed to possesses supernova power [1]. In India coal-based thermal power plants have been a major source of power generation, where 75% of the total power obtained is from coal-based thermal power plants. The majority of thermal power plants (about 84%) are running on coal with 70 billion tons of coal reserve, while the remaining 13% run on gas and 3% on oil [2]. In India, unlike in most of the developed countries, ash content in the coal used for power generation is 30–40%. In order after USSR, USA and China, India ranks fourth in the world in the production of coal ash as by-product waste [3]. Annually thermal power plants are generating about 112 million tons of fly ash as a byproduct of coal combustion in India. Where the quality of fly ash depends on coal type, coal particle fineness, percentage of ash in coal, combustion technique, air/fuel ratio, and boiler type [4].

Coal contains significant quantities of various trace elements. At the time of coal combustion, the trace elements associate with the surface of the ash particles due to evaporation and condensation. The characteristics of the coal used and the type of the installation employed in generating the solid combustion wastes have a direct influence on chemical and mineralogical composition of fly ash [5]. Fly ash has been successfully used for many years as a clinker addition in the manufacturing of portland cement. Other than that in awide range of applications of fly ash is including building material applications, asphalt, concrete pavements, soil stabilization, road base, structural fill, embankments, mine reclamation, mineral fillers or fertilisers and small scale applications such as production of zeolites and geopolymers. The unused fly ash is disposed into holding ponds, lagoons, landfills and slag heaps. Disposal of huge amounts of fly ash in landfills, and surface impoundments or its reuse in construction materials is of environmental concern [6].

In combustion process, Mn, Ba, V, Co, Cr, Ni, Ln, Ga, Nd, As, Sb, Sn, Br, Zn, Se, Pb, Hg, and S in coal are volatile to a significant extent. However, the elements Mg, Na, K, Mo, Ce, Rb, Cs, and Nb appear to have smaller fractions volatilized during combustion, whereas Si, Fe, Ca, Sr, La, Sm, Eu, Tb, Py, Yb, Y, Se, Zr, Ta, Na, Ag, and Zn are either not volatilized or show only minor trends related to the geochemistry of mineral matter [7]. Some elements contained in fly ash are likely to be released from the storage/disposal/application site when ash comes in contact with water. These elements can be leached in higher concentrations than drinking water standards and can cause contamination in drinking water sources (pollute both ground and surface waters). Fly ash contains trace amounts of toxic metals that may have negative effects on soil, human and plants [8].

Leaching is the process by which soluble constituents are dissolved from a solid material (such as rock, soil, or waste) into a fluid by percolation or diffusion. Thus, when fill materials come into contact with liquid (including percolating rainwater, surface water, groundwater, and liquids present in the fill material) constituents in the solid phase will dissolve into the liquid forming a leachate. The extent to which the constituents dissolve into the contact liquid will depend upon site and material specific conditions (chemical, physical, and biological factors) and the length of time involved [9]. Leaching reactions are characterized as hydrolysis, caustic (alkaline), acidic, or oxidative reductive. In addition to water, acids and bases are commonly used as leaching agents. This process can be complicated by secondary reactions, such as precipitation, adsorption, or the formation of complexes [10].

2. MATERIALS AND METHODS

Site: Ramagundam Super Thermal Power Station is a coal-fired thermal power plant which is fully owned by NTPC Ltd. located in KarimNagar district of Andhra Pradesh. It has installed capacity of 2600MW comprising of 3 units of 200MW (stage-I) and 4 units of 500MW (stage-II & III). Coal which is used in Ramagundam power plant has following specification: Fixed Carbon – 42%, Ash – 37%, Volatile Material – 18%, Moisture – 3%, Gross Calorific Value – 3800-4500 kcal/kg. Annual ash production in plant is 36.5 lakh tonnes. Here, 53.41 % ash is utilized and rest of the 46.59% is pumped in a slurry form through pipe lines to the ash pond located near Kundanpalli which is about 5 km away from the power station.

Sampling: For this study, 9 types of samples were taken which include samples from plant, nearby ash pond and villages around ash pond. For analysing toxic impact of leaching in water bodies near the ash dumps, 26 samples of ground water and 9 samples of surface were collected from the villages falling in 10 Km radii of ash ponds. For ground water sampling 5 villages in 3 Km radii, 10 villages in 3-6 Km radii and 11 villages in 6-10 Km radii were selected. For surface water 7 samples were taken from villages and 2 samples from Godavari River.

Metal Determination: Fly Ash and water samples collected from the ground as well as surface water sources in the vicinity of ash disposal sites and in radii of 10 Km were analysed for heavy metal (As, Ni, Hg, Cd, Pb, Mn, Cr, Cu, Zn, Co, Al, Fe, B) concentration on Atomic Absorption Spectroscopy (AAS).

Determination of Flouride: All the water and fly ash samples were analysed for Flouride as F concentration by SPADNS colorimetric method (APHA) which is based on the reaction between fluoride and a zirconium-dye lake [11].

Leaching Test: Column Test method (Meteoric Water Mobility Procedure (MWMP)) was selected for carrying out the leachate study, since it is best suitable to know the short-term effect of leaching. Before proceeding for the test fly ash samples, collected at each stage, were mixed to get a homogeneous mixture. In all cases the moisture was maintained below 0.25%. Particle size varies from coarse sand to fine silt and remains below 3 mm size.

3. RESULTS AND DISCUSSION

Fluoride and Heavy Metals in ground water sources: Concentration of heavy metals and fluoride which exceed the permissible limit in ground water samples near the ash pond and at the surrounding villages are shown in figure 1. The elements like Mg and Al found in higher concentration than permissible limit in more than 70% samples, while Fluoride and Manganese also exceed the permissible limit in more than 25% samples. The concentration of Ni, Cu, Zn, Fe and B is lower and nearly similar in the water samples in all locations, while As, Cr, Cd, Hg and Pb are absent in all water samples.

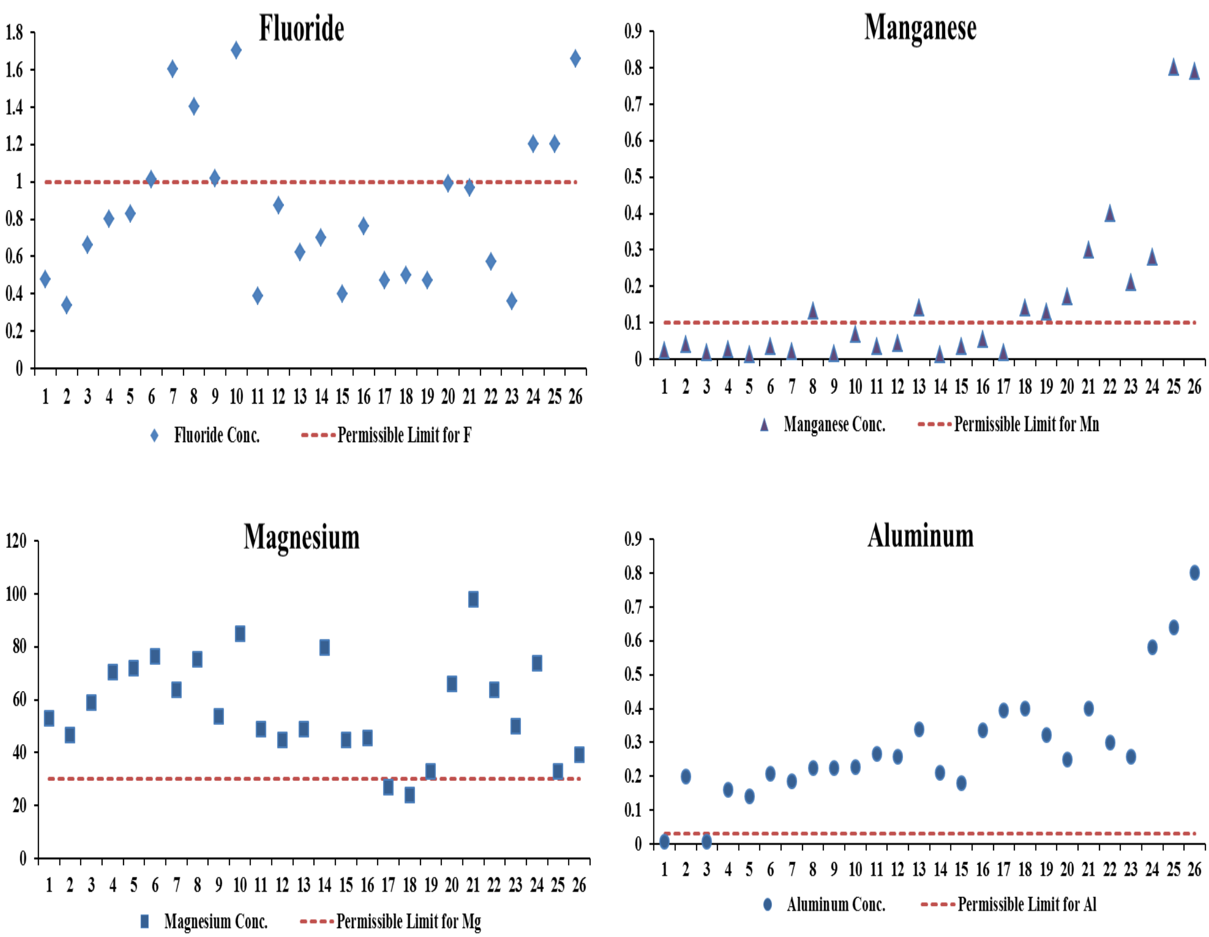

Figure 1: Concentration of different metals in ground water sources in radii of 10 Km from Ash Ponds (all the values in mg/L)

Fluoride and Heavy Metals in surface water sources: Concentration of heavy metals which exceed the permissible limit in surface water samples of surrounding villages of ash pond and Godavari River are shown in figure 2. Aluminum found in higher concentration than permissible limit in more than 70% samples, while Magnesium, Chromium and Manganese also exceed the permissible limit in more than 25% samples. The concentration of Ni, Cu, Zn, Fe and B is lower and nearly similar in the water samples in all locations, while As, Hg, Cd and Pb are absent in all water samples.

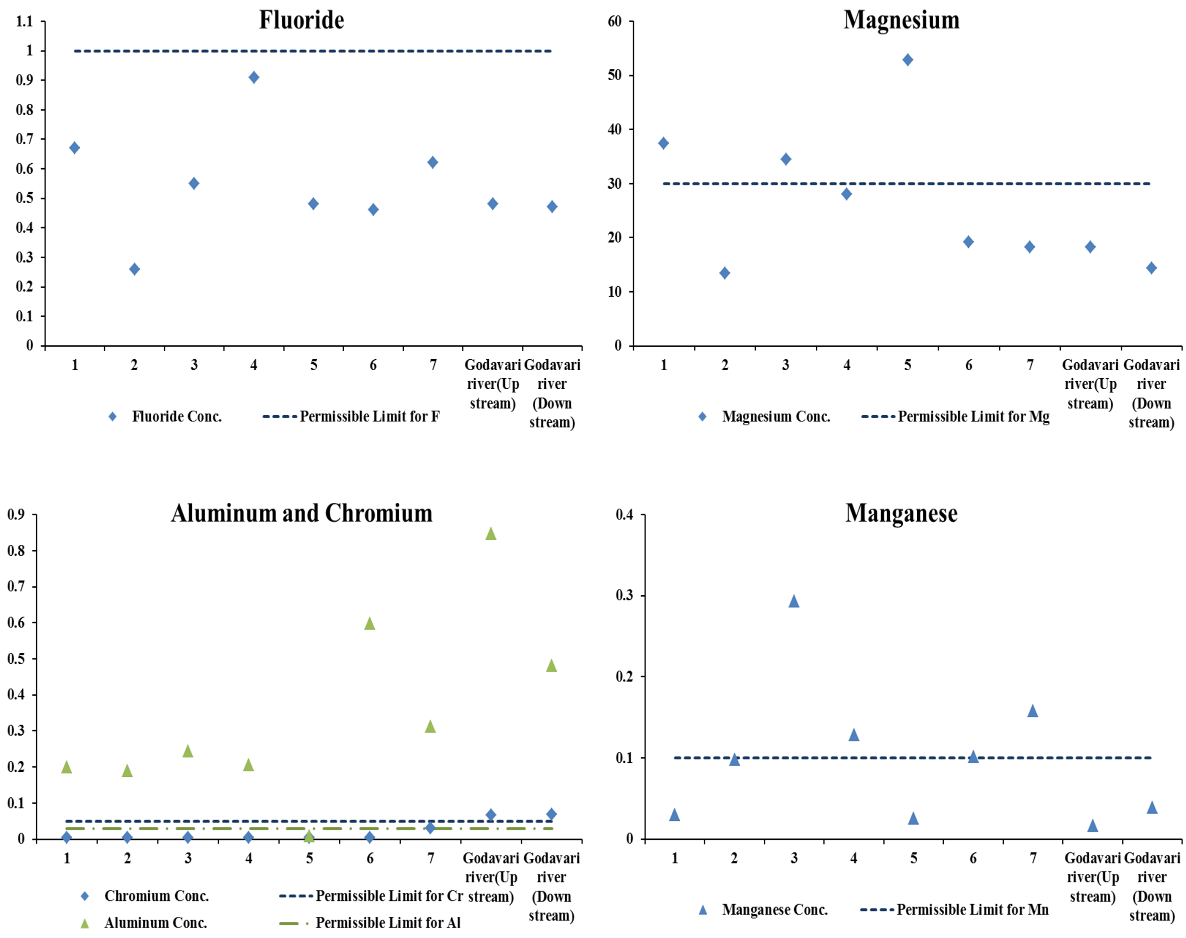

Figure 2: Concentration of different metals in surface water sources near Ash Ponds(all the values in mg/L)

*Leaching test results:*Leaching test was performed by Meteoric Water Mobility Procedure for Cd, Total Chromium, Ni, As, Pb, Zn and Cu. Test was performed with variation in pH and temperature. The concentrations of the heavy metals that were leached out with meteoric water as a result of column leaching test are shown in Table 1. Chromium and Nickel did not leach from the fly ash samples because initially they were not present in fly ash and bottom ash samples as shown in table 2. Arsenic and Zinc showed solubility with water and was leached in higher concentration at acidic pH and higher temperature. The leached Cu concentration was low in comparison with As and Zn, this is probably because Cu is precipitated as it's insoluble hydroxides. Around 10% of total Cd was solubilized in the acidic pH range. The elements in the ash particles were mainly associated with the surface, and these surface-associated fractions might dominate the leachate chemistry at the early stages of fly-ash disposal in contact with water [12]. However, the elements incorporated within the interior of the fly ash dissolved at a slower rate compared with the readily leachable surface associated elements.

Table 1: Leaching results of fly ash (*BDL = Below Detection Limit*)

Sr no	Parameters	Unit	Leachate Analysis								
			pH 5.5			pH 6.5			pH 8.5		
			28°C	30°C	34°C	28°C	30°C	34°C	28°C	30°C	34°C
1	Cadmium as Cd	mg/Lit	0.085	0.1	0.11	BDL	0.03	0.07	BDL	BDL	BDL
2	Total Chromiun as Cr	mg/Lit	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
3	Nickel as Ni	mg/Lit	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
4	Arsenic as As	mg/Lit	1.21	1.72	1.92	0.42	0.68	0.75	BDL	BDL	BDL
5	Lead as Pb	mg/Lit	0.97	1.21	1.18	0.48	0.61	0.65	0.07	0.09	0.03
6	Zinc as Zn	mg/Lit	3.25	3.6	3.9	1.05	1.05	1.08	0.22	0.26	0.28
7	Copper as Cu	mg/Lit	0.035	0.075	0.08	0.06	0.08	0.08	0.03	0.04	0.06

As shown in table 2 concentration of Fluoride, Cobalt, Manganese, Magnesium, Lead Zinc, Arsenic, Mercury and Boron in fly ash and bottom ash samples are very high. Cadmium and Copper in samples are in lower concentration, while Chromium, Nickel, Selenium, Barium and lithium are absent in samples.

Table 2: Heavy metals concentration in fly ash and bottom ash

Sr. No.	Parameters	Unit	Fly ash	Bottom ash
1	Fluoride as F	mg/kg	40	45
2	Cadmium as Cd	mg/kg	1.88	1.79
3	Cobalt as Co	mg/kg	18.84	11.58
4	Chromium as Cr	mg/kg	BDL	BDL
5	Copper as Cu	mg/kg	0.238	0.078
6	Manganese as Mn	mg/kg	39.82	26.1
7	Magnesium as Mg	mg/kg	56.6	70.2
8	Nickel as Ni	mg/kg	BDL	BDL
9	Lead as Pb	mg/kg	12.34	10.04
10	Zinc as Zn	mg/kg	35.12	25.4
11	Arsenic as As	mg/kg	25.2	29.7
12	Mercury as Hg	mg/kg	40.2	19.3

13	Selenium as Se	mg/kg	BDL	BDL
14	Beryllium as Be	mg/kg	10.8	5.6
15	Barium as Ba	mg/kg	BDL	BDL
16	Lithium as Li	mg/kg	BDL	BDL
17	Boron as B	mg/kg	7.53	3.76

4. CONCLUSIONS

Ashes produced by coal thermal power plants are considered as a waste and need to be properly disposed to avoid environmental contamination, so it is important to know the leaching potential of toxic elements in ash.

The following conclusions can be made from this study:

- Comparision of ground water and surface water samples near the ash ponds and at the surrounding villages shows that the concentration of heavy metals (except Mg, Mn, Al and Cr) is within the permissible limits of India standards IS: 10500 and WHO limits for drinking water quality.
- Concentration of Fluoride is found more than permissible limit in ground water samples
- The toxicity and metal concentrations of the fly ash increased with decreasing pH and increasing temperature
- The results shows that 5-30% of toxic elements (As, Cu, Pb) are leachable and around 10% of total Cd was solubilized in the acidic pH range
- A combination of safe disposal technique and increased utilization is required to combat the environmental problem associated with fly ash generation in India.
-

REFERENCES

[1] Sharan A, Sharma A, Govind P. *Im-pact of coal mining on social ecology- A tentative note*. In: Socio-economic Impact of Environment. Akashi Publishing House; New Delhi:46-65.

[2] Chandra A, Chandra H. *Impact of Indian and imported coal on Indian thermal Power Plants*. J. Sci. Ind. Res. 2004; 63: 156.

[3] Senapati M R. *Fly ash from thermal power plants – waste management and overview.* Current Science 2011; 100(12):1791-1794.

[4] Dhadse S, Kumari P, Bhagia L. J. *Fly ash characterization, utilization and Government initiatives in India- A review*. J. Sci. Ind. Res. 2008; 67: 11-18.

[5] Benito Y, Ruiz M, Cosmen P, Merino J. L. *Study of leachates obtained from the disposal of fly ash from PFBC and AFBC processes*. Chem. Eng. J. 2001; 84: 167-171.

[6] Piekos R, Paslawska S. *Leaching characteristics of fluoride from coal fly ash*. Fluoride 1998; 31:188-192.

[7] Iyer R. *The surface chemistry of leaching coal fly ash*. J. Hazard. Material. B93 2002; 321-329.

[8] Mehara A, Farago M E, Banerjee D K. *Impact of fly ash from coal fired power stations in Delhi, with particular reference to metal contamination*. Environ. Monit. Assess. 1998; 50:15-35.

[9] Pendowski J J. *An Assessment of Laboratory Leaching Tests for Predicting the Impacts of Fill Material on Ground Water and Surface Water Quality*. Department of Ecology, Olympia, WA; 2003.

[10] Kim A G. *Fluid Extraction of Metals from Coal Fly Ash: Geochemical Simulation of Natural Leaching*. Ph D Thesis, College of the Arts and Sciences, University of Pittsburgh; 2002.

[11] APHA, AWWA and WEF, 1998, *Standard methods for the examination of wastewater*, 20th edition, American Public Health Association, American Water Works Association, and Water Environmental Federation, Washington. D.C.

[12] Choi S K, Lee S, Song Y K, Moon H S. *Leaching characteristics of selected Korean fly ashes and its implications for the groundwater composition near the ash mound*. Fuel 2002; 81:1083-1090.

[13]