Innovations

Phytoremediation an Approach towards Management Practices of Fly Ash Dumpsite

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Abstract:

Coal-based power generation is a principal source of electricity in India and many other countries. Among the coal combustion by products, coal fly ash contributes almost 15-30%. Coal fly ash and fly ash leachate is highly toxic to terrestrial and aquatic ecosystem due to the presence of toxic level of heavy metals. Conventionally fly ash is deposited in the nearby land without ensuring proper disposal methods. Contamination of ground and surface water through leaching of heavy metals effects the ecosystem. Phytoremediation is a cost effective environment friendly technique which can be used for managing fly as dumpsite. This review deals with the potential of phytoremediation technique in restoring the fly ash dumpsite.

Key words: *Fly ash, Heavy Metal, Leaching, Phytoremediation*

Introduction:

Coal-based thermal power stations have been the major source of power generation in India and many other countries. Nearly 15–30% of the total amount of residue generated during burning of coal in thermal power plants constitutes fly ash. Lower quality lignite, sub bituminous coal which is mostly used in thermal power plants of India generates 78.2-90.5% fly ash fraction. In India, annually more than 100 million tons of FA is produced which is estimated to exceed 140 million ton per annum by 2020 (Pandey et al., 2009a). In India, major sector of fly ash utilization is as follows: cement manufacture/substitution 49%, road and embankments 21%, low lying area filling 17%, dyke rising 4%, brick manufacturing 2%, mine filling 2%, agriculture 1%

and others 3%. Despite of initiative to utilize fly ash there is a significant discrimination is present between the utilization and production. Fly ash is reported to contain several toxic heavy metals like As, Cu, Cr, Zn, Pb etc. (Jana et al. 2017). These metals can cause damage to the normal cellular function and concentrate within plant body leading to toxic effects (Gill and Tuteja 2010). To prevent it from being air borne, FA dumpsites are generally kept wet which also leads to leaching of toxic metals from FA and contamination of surface and ground water. Contamination of ground and surface water of nearby areas of FA dumpsite is well documented in literature (Praharaj et al., 2002). Leaching of heavy metals can contaminate surface and ground water leading to aquatic pollution. As a result, FA and FL pose threat to the terrestrial and aquatic ecosystem. So, it is necessary to find ways to remediate fly ash dumpsite.

Phytoremediation basically refers to the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environments (Greipsson, 2011). It is an integrated multidisciplinary technique to the cleanup of contaminated soils and water bodies (Cunningham and Ow, 1996). Plants directly or indirectly absorb, sequester, and/or degrade the contaminant with the help of irrigation, fertilization, and cropping schemes. By growing plants over a number of years, the aim is to either remove the pollutant from the contaminated matrix or to alter the chemical and physical nature of the contaminant within the soil so that it no longer presents a risk to human health and the environment (Cunningham and Ow, 1996). In this review we will look out the potential of phytoremediation in management of fly ash dumpsite.

Characterization of fly ash

The physical properties of FA are dependent on the composition of the parent coal, conditions during combustion, efficiency of emission control devices, storage and handling of the by products and climate (Adriano et al., 1980). Coal fly ash occurs as very fine particles having an average diameter of <10 μm and has low to medium bulk density, high surface area and light texture (Jala and Goyal, 2006). Mostly spherical to some irregular particles can be observed in FA aggregates collected from different sources. Mineralogically, FA is composed of three major matrices: glass, mullite-quartz, and magnetic spinel (Hulett and Weinberger, 1980). Major constituents of matrix are magnetite, hematite, ferrite, and γ-Fe_2O_3 (Hulett and

Weinberger, 1980, Hansen et al., 1981) whereas gypsum, calcite, ferrous carbonates and manganese oxides contribute to a lesser extent (Cox et al., 1978, Henry and Knapp, 1980, Bauer and Natusch, 1981). Elemental analysis of FA reveals high amount of silica (Si), carbon (C), aluminium (Al), iron (Fe), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), titanium (Ti), manganese (Mn) and mostly in their oxidative states. Among the essential elements carbon is the most prevalent as main composition of coal is carbon. Most of these elements are beneficial for plant growth which encourages the use of FA in agriculture. Presence of nitrogen (N), silica (Si), phosphorus (P), calcium (Ca), magnesium (Mg), sodium (Na), iron (Fe) in coal fly ash along with carbon encourages its use as fertilizer. Besides, FA also contains high concentration of trace elements like Cu, Cd, Pb, Zn, Se, Ni, Co, Cr, B. High concentration of these trace elements in FA makes it a potent environmental pollutant (El-Mogazi et al., 1988, Chakraborty et al., 2009, Pandey et al., 2009a, Jala and Goyal, 2006, Baba et al., 2008). Trace elements like As, Se, Mo, Cd and Zn is mostly present in the surface area whereas Cr, Cu and Pb are evenly distributed both in particle core and surface. Presence of radionuclides like 226Ra, 228Ac and 40K was recorded in soil treated with FA. (Mittra et al. 2005, Dhadse et al., 2008).Presence of mutagenic/carcinogenic compound like polycyclic aromatic hydrocarbons (PAH) also has been identified in extracts from a wide variety of ashes (Low et al., 1986).

Effect of fly ash on plant system

Coal fly ash is considered as hazardous waste product due to the presence of heavy metals along with essential macronutrients. Controlled and uncontrolled disposal of coal fly ash and its application to agricultural soils contributes towards contamination of hectors of agricultural lands. Inorganic wastes commonly containing heavy metals are serious threat to ecosystem as soil microorganisms are incapable of breaking them. Leachate from these landfills formed by rainfall may have adverse impact on aquatic biota, wildlife, and surrounding vegetation, due to the elevated levels of heavy metals present (Tiwary, 2001). Although many metals are essential, all metals are toxic at higher concentrations. These heavy metals tend to accumulate within plant body when they are grown on lands contaminated with coal fly ash (due to its use as fertilizer and land filler) also provides risk of human exposure. Moreover leaching through rain water and seepage of heavy metals due to insufficient lining of ash pond also contaminate ground and surface water. Throughout literature several field and lab based experiments have been conducted to assess the toxic effects of FA on the growth and biomass of the plant. FA is reported to induce significant inhibition of growth on higher concentrations whereas acts as growth modulator at lower concentrations. FA exposed plants showed biphasic responses in photosynthetic pigment level. Besides, response to FA stress varies between genus and species (Mishra and Shukla 1986; Khan et al. 1996; Gupta et al. 2010; Agarwal et al. 2011). Reports on the DNA damaging effects of FA and FL are scarce though most of the reports are concerned with the growth, yield and biomass of the plants. Studies revealed that FA and FL is highly genotoxic and mutagenic to both plant and animal system (Chakraborty and Mukherjee 2009; Jana et al. 2017). FA is a potent oxidative stress inducer because of the presence of high level of heavy metals. The imbalance in ROS levels is responsible for the oxidative stress. An increase in lipid peroxidation, cysteine and non-protein thiol level can be noted. Significant increase in antioxidative enzyme activity was commonly noted in plants exposed to fly ash.In most cases, total protein content shows a decrease in exposed plants. (Dwivedi et al., 2007, Gupta et al., 2007b, Pandey et al.,2010). Osmolyte like proline also found to be accumulated in exposed plants (Qadir et al. 2016)

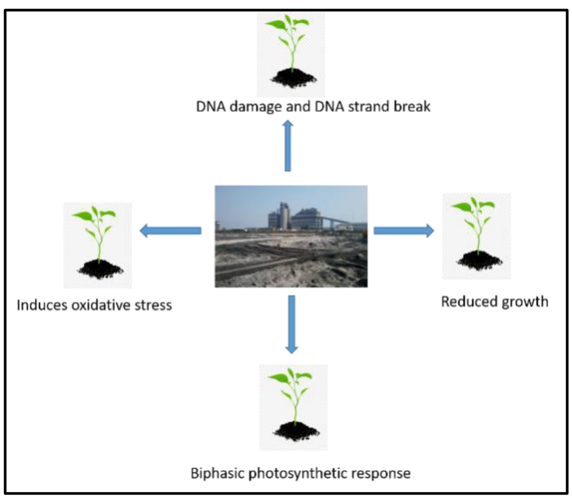

Figure 1: Plant response when exposed to fly ash

Fly ash management Practices:

Coal fly ash is commonly disposed in nearby areas of thermal power plant. As coal fly ash comprises very fine particles, they are generally kept wet to prevent the loose particles from being airborne. This is known as wet disposal technique. Most of the power plants in India use wet disposal system where coal fly ash is being converted to slurry form and dumped in large settling pond called as ash pond/ash mound which ultimately strikes negative impact on the environment. Ash ponds, the dumpsite of coal fly ash should be provided with lining which was not properly followed in most cases in India. Since soil below the impoundments is always saturated and under considerable hydraulic head, the inefficiently lined ponds provide a great opportunity for the groundwater contaminants to seep in (Theis et al. 1978). In addition to this, discharge of rain water and run off from the ash mound areas into surface water bodies can also be a source of water pollution. Leaching is the most likely path by which coal bottom ash constituents would become mobile, environmental contaminants. In India, Ministry of Environment & Forests (MOEF) and Ministry of Power (MOP) started fly ash utilization programme (FAUP) in 2002 to increase the utilization of huge amount of coal fly ash. The main objective of this programme was to make coal fly ash a useful by-product, to reduce environmental pollution and land requirement for coal fly ash disposal and to economise construction. Globally, more than 30% of the total annual coal fly ash produced is utilized (Haynes, 2009). In the recent past many applications have been identified due to the presence of basic mineral elements resembling earth‘s crust, which makes them excellent replacement for natural materials. They can be used as a substitute for Portland cement in manufacturing roofing tiles and as structural fills, preparing brick, sheetrock, road construction, land filling, agricultural fertilizer and soil amendments (Dhadse et al., 2008).

Phytoremediation- an environment friendly approach

Phytoremediation is an integrated part of bioremediation which deals with the use of plants for environmental clean-up. It is an attractive, environmental friendly and cost effective approach to remediate metals and radionuclide from polluted soil and water bodies (Entry et al., 1997, Zhu and Shaw, 2000). Plants have constitutive and adaptive mechanisms for accumulation or tolerance of high contaminant concentration in their rhizoshpere (Eapen et al., 2007). A phytoremediation system uses on the relationship among plant and its ecological niche that have evolved naturally in wetlands and upland sites over millions of years. This makes the plant as a potential organism to extract, concentrate and metabolize materials from their habitat (Salt et al., 1995). As stated earlier besides being cost effective phytoremediation technologies have several other advantages. Advantages and disadvantages of phytoremediation are listed below. Phytoremediation is an umbrella term which covers several plant-based approaches for cleaning up contaminated environments. Depending on the contaminants, the site conditions, the level of clean-up required, and the types of plants, phytoremediation technology can be used for containment (phytoimmobilization and phytostabilization) or removal (phytoextraction and phytovolatilization) purposes. (Eapen et al., 2007). There are different plant-based technologies of phytoremediation. They are namely phytoextraction, phytostabilization, rhizodegragdation, phytodegradation and phytovolatilization and each of them having a different mechanism of action for remediating metal-polluted soil, sediment, or water.

Application of phytoremediation in fly ash dumpsite

Plant species selection is an important factor in determining the success of phytoremediation on FA lagoons. The species selected should be able to grow in enriched levels of trace elements and a highly alkaline environment. The ideal plant species for phytoremediation should have high biomass with high metal accumulation in the shoot tissues (McGrath et al., 2002). For this reason, tree species are potent candidates for phytoremediation due to the presence of long root system and huge biomass. Plants with high root biomass are also a potent candidate for phytoremediation. Members of Poaceae like *Chrysopogonzizanioides*, *Saccharum munja*, *Saccharum spontaneum*also accumulate heavy metals in their tissue leading towards mitigation of polluted soil. The deep root system of Poaceae also makes them a potent candidate for Phytoremediation (Pandey et al., 2009). Besides, hyperaccumulator species despite of their smaller biomass can accumulate and tolerate high amount of heavy metal. Some of the plants belonging to Brassicaceae such as *Alyssum* species, *Thlaspi*species and *Brassica juncea*, Violaceae such as *Viola calaminaria*, Leguminosae such as *Astragalus racemosus*are known to take up high concentrations of heavy metals and radionuclides (Reeves and Baker, 2000). From the results of different studies, it can be said that to overcome this environmental problem, the revegetation of FA dykes/landfills with tolerant plants is one of the cheap alternatives. It may check atmospheric pollution, leaching of toxic metals and develop a bioaesthetic pleasant environment for local inhabitants (Rai et al., 2004a). Several field studies including survey of plants growing on fly ash lagoons have been conducted on fly ash dumpsites to find the potential of phytoremediaton.

A field study was conducted in the FA lagoons of Santandih Thermal Power Plant located in West Bengal (India) to find out bioaccumulation of metal in root and shoot portion of the naturally growing vegetation. Five dominant vegetation namely, *Typha latifolia, Fimbristylisdichotoma, Amaranthus defluxes, Saccharum spontaenum*and *Cynodondactylon*were evaluated for metal uptake. The field study revealed that *T. latifolia* and *S. spontaenum*plants are more potent phytoremediant compared to other plants of the study (Maiti and Jaiswal, 2008). Another field study was carried out by Dwivedi et al., 2008 to screen native plants growing on fly-ash contaminated areas near National Thermal Power Corporation, Tanda, Uttar Pradesh, India with a view for using them for the eco-restoration of the area. A total number of 17 plants (9 aquatic, 6 terrestrial and 2 algal species; listed in table) were collected and screened for heavy metal (Fe, Zn, Cu, Mo, B, Si, Al, Cr, Pb, Cd, Hg and As) accumulation. Among the terrestrial plant species *Eclipta alba* was the most efficient bioaccumulator. In general, the maximum levels of most metals were found in terrestrial plants while the lowest in algal species. However, translocation of the metals from root to shoot was found to be higher in aquatic plants than terrestrial ones.

Jambhulkar and Juwarkar 2009 reported that *Cassia siamia*can be used as a potential phytoremediant as it act as a hyperaccumulator plant.Pandey et al. 2012 and Kumar et al. 2015 reported that *Saccharammunja*and *Cynodondactylon ,m*embers of Poaceae, were found to grow on FA lagoon naturally. They can be used for eco restoration of fly ash dumpsite. Members of Poaceae*Cynodondactylon (L.) Pers., Cyperus rotundus L., Dactylocteniumaegyptium L., Digitariasanguinalis L.* also recognized as potential plants for ecological restoration of FA dumps. (Yadav et al. 2022). They also reported dominance of Tree species like *Acacia nilotica* L., herbaceous species like *Acmella oleracea Trianthemaportulacastrum L., Typha latifolia L. and Portulaca oleracea L* in fly ash disposal area of Koradi Thermal Power Plant, Nagpur in a survey during 2019–2020. Shakeel et al. 2023 found that *Bambusabambos* is the most potent bamboo species for phytoremediation of fly ash dumpsites due to its high biomass which results into high level of heavy metal accumulation. Poaceae family plays an pivotal role in eco restoration of fly ash dumpsite as we have discussed in previous paragraph. Large biomass, extensive root system helps in phytostbilization and phytoextraction of pollutants from the dumpsite.

Erigeron canadensis member of the family Asteraceae, was grown on FA landfill of power plant of Kolubara, Serbia. Plant was found to be suitable for phytostabilization of Al, Fe, Cr and Co whereas phytoextraction of Cd and Zn to the inflorescence was observed. Regarding its dominance in vegetation cover and abundance, *E. canadensis* L. can be considered adequate for phytoextraction of Cd and Zn from coal ash landfills at Kolubara (Krgović et al., 2015). In another field experiment was conducted with three naturally growing plants *Ipomoea carnea*, *Lantana camara* and *Solanum surattense*in FA dumpsite of Patratu thermal power station, Jharkhand, India. *Solanum surattense*was reported as phytostabilizer and other two species as phytoextractor of metal for FA dumpsite reclamation (Pandey et al., 2016). Similar findings were reported by Kisku et al. 2018 from ash dykes of Singaruil.

Table 1: Field study of management of fly ash dumpsite by phytoremediation

Sl. No.	Plant species	Treatment	Remarks	Reference
1.	*Typha latifolia, Fimbristylisdichotoma, Amaranthus defluxes, Saccharum spontaenum, Cynodondactylon*	FA lagoons of Santandih Thermal Power	• Bioaccumulation of metals in were within toxic limits. • *T. latifolia* and *S. spontaenum* plants possesphytoremediatonpot entential	Maiti and Jaiswal 2008
2.	**Aquatic plants:***Marsiliaquadrifolia, Ranunculusscloralus,*	FA contaminated are, National	• Most efficient metal accumulator among 9 aquatic plants, *Eclipta*	Dwivedi et al. 2008

	Ipomoea aquatica, Lippianodiflora, Potamogetonpectinatus, Eichhornia crassipes, Hydrorhizaaristata, Hydrilla verticillata, Ceratophyllumdemersum, **Terrestrial plants:** *Parthenium hysterophorus, Solanum nigrum, Limnanthes* sp. *Equisetum ramosysma, Saccharum munja, Eclipta alba* **Algal species:***Spirogyrabiformis, Phormidiumpapyraceum*	Thermal Power Corporation, Tanda, Uttar Pradesh	*alba* among 6 terrestrial plants and *Phormediumpapyraceum* between 2 algal species.	
3.	*Azadirecta indica, Cassia siamea, Eucalyptus hybrida, Emblica officinalis, Tectona grandis, Dendrocalamusstrictus, Delbergia sissoo* and *Pongamia pinnata*	FA dump site	• Study revealed that *C. siamea* could be used as a hyper-accumulator plant for bioremediation	Jambhulkar and Juwarkar 2009
4.	*Typha* sp., *Datura stramonium*, *Parthenium hysterophorus*, *Lycopersicum esculentum, Brassica campestris* and *Croton*	FA pond	• Higher level of metal accumulation was noted in in upper parts of all plants. • These plants can be considered as	Singh et al. 2010

	bonplandianum.		accumulator species	
12.	*Pteris vittata*	FA dumpsite	• Significant accumulation of metal in the above ground parts of the plant	Kumari et al. 2011
13.	*Ipomoea carnea*	FA deposites	• *I. carnea* was identified as an effective plant for phytoremediation in harsh environmental conditions of abandoned FA deposits	Pandey 2012a
14.	*Saccharum munja*	FA lagoons of NTPC Unchahar, India	• Plants can be used to rehabilitiate FA dumpsites.	Pandey et al. 2012
15.	*Riccinus communis*	FA deposition	• *R. communis* can be used as a commercial crop for phytostabilization and revegetation of FA disposal sites in tropical and sub-tropical region.	Pandey 2013
18.	*Erigeron Canadensis*	FA landfill, Kolubara, Serbia	• Plant is adequate for phytoextraction of Cd and Zn.	Krgović et al. 2015
19.	*Saccharammunja* and *Cynodondactylon*	FA lagoon	• Plants are suitable for phytoremediation of FA lagoon	Kumar et al. 2015

20.	*Ipomoea carnea*, *Lantana camara* and *Solanum surattense*	FA dumpsite of Patratu thermal power station,	• *Solanum surattense*can be used as phytostabilizer and other two species as phytoextractor of metal.	Pandey et al. 2016
21.	*Ipomea carnea, Solanum nigrum, Sachharummunja, Typha angustifolia, Cynodondactylon and Parthenium hysterophorus*	FA dumpsite Singrauli	• *Ipomea carnea*showed highest absorption potential.	Kisku et al. 2018
22.	*Acacia nilotica L., Acmella oleracea L., Bacopa monnieri L., Cynodondactylon (L.) Pers., Cyperus rotundus L., Dactylocteniumaegyptium L., Digitariasanguinalis L., Trianthemaportulacastrum L., Typha latifolia L. and Portulaca oleracea L.*	FA dumpsite Koradi Thermal Power Plant, Nagpur, Maharashta	• Naturally growing plant species on fly ash dykes are usefull in eco restoration.	Yadav et al. 2022
23.	*Bambusabalcooa, B. vulgaris 'wamin', Bambusabambos, and Bambusa vulgaris*	FA dumpsite	• *Bambusabambos*is most efficient phytoremidant	Shakeel et al. 2023

Conclusion:

Dependency on coal as a major source of energy resulted into a higher production of fly ash. Due to lack of proper management of fly ash dumpsite, contamination of nearby soil and water is a grave issue. Phytoremediation is an emerging technique which can help in clan up of heavy metal contaminated dumpsite. Fly ash a heterogeneous waste product comprising heavy metals and aromatic compounds. Studies on fly ash dumpsites have shown that different members of Poaceae, Asteraceae can be used for reclamation of fly ash dumpsite. Plants with higher biomass are much suitable for this purpose compared to other. Tree species are found to be more efficient compared to herb and shrub.As the technique is quite cost effective it can be widely used for remediation purpose in future. Thus, eco restoration by phytoremediation can provide an environment friendly and aesthetically pleasing approach for management of fly ash dumpsite.

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