ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

REVIEW ARTICLE

Evolution of fly ash management strategies — a review of selected value-added fly ash utilization approaches

Nisha Dawle[1], Shaila K. Khadse[1], P. V. Patil[1],* Deepa Panhekar[2]

1. LIT, RTM Nagpur University, Nagpur
2. Department of Chemistry, Dr. Ambedkar College, Deeksha Bhoomi, Nagpur, India

Manuscript Info

Manuscript History:

Received: 22 December 2013
Final Accepted: 22 January 2014
Published Online: February 2014

Key words:
Fly ash generation, management, quality of coal, phytoremediation, bio-transformation

******Corresponding Author***

Deepa Panhekar

Abstract

The current state of industrial activity indicates that there would not be any remarkable drop in fly ash generation in near future. Despite the fact that there are many noticeable technological innovations for effective fly ash management, the problem still persists. The quantum of fly ash generation is huge and the available methods for its management appear to be inadequate. Though, it has been widely used in different sectors, its use has been found to be limited and hence, an attempt has been made in this study to review the various approaches used by the researchers. The literature published in the standard journals was reviewed using the principles of deductive reasoning. The many approaches used by researchers are testimony to the fact that fly ash management is very complex, especially because of the quantity of fly ash generation, which is the function of quality of coal burnt (and the ash content of coal). On the basis of the review, the study concludes that the few attempts made to study the fly ash management mainly focus on its (fly ash) physical management (backfilling and reclamation). In addition to this, the literature strongly indicates that phytoremediation can be successfully used for fly ash management, as numerous plant species have been reported as possible agents for facilitating the bio-transformation of the fly ash.

1.0 Introduction

The demand for energy is increasing with a very fast pace. This demand is significantly higher in the developing countries such as India and China. In India, thermal power plants constitute 65% of the installed capacity (of 185.5 Gigawatt, as of November 2011). Though India's electricity generation capacity is increasing at a very fast pace, still many areas do not have uninterrupted power supply. In view of the current electricity generation in India, the thermal power plants present multiple challenges like, the air pollution problems, fly ash, etc. Though there are noticeable technological improvements in the field of minimizing air pollution (and carbon sequestration), same is not true for the fly ash management. The conventional practices of fly ash management have not changed significantly and it (fly ash) still offers a persistent problem. González et al. (2009) have reported that the disposal of coal fly ash can have severe impacts in the environment such as a potential groundwater contamination by the leaching of heavy metals and/or particulate matter emissions; making it necessary to treat or reuse them

1.1 Status of Fly ash generation

Thermal Power stations using pulverized coal or lignite as fuel generate large quantities of ash as a by-product. In India, there are about 82 power plants, which form the major source of fly ash. With the commissioning of super thermal power plants and with the increasing use of low grade coal of high ash content, the current production of ash is about 100 million tonnes per year. This figure is likely to go up and pose serious ecological problems.

Although the scope for use of ash in concrete, brick making, soil-stabilization treatment and other applications has been well recognized, only a small quantity of the total ash produced in India is currently utilized in such applications. Most of the ash generated from the power plants is disposed off in the vicinity of the plant as a waste material covering several hectares of valuable land. The bulk utilization of ash is possible in two areas, namely, ash dyke construction and filling of low-lying areas. Coal ash has been successfully used as structural fills in many developed countries. However, this particular bulk utilization of ash is yet to be implemented in India. Since most of the thermal power plants in India are located in areas where natural materials are either scarce or expensive, the availability of fly ash is bound to provide an economic alternative to natural soils. In the backdrop of above information, a systematic review was carried out to study the recent history of fly ash management and identification of the research gaps that can be discovered for delineating a roadmap for fly ash management.

2.0 Materials and Methods

In the present study, literature review was carried out to identify the previous research efforts and directions related to fly ash management. The objective was to identify the research gaps and highlight research motivations for further studies. To the extent possible, care was taken to reproduce the original terminology used by the authors to preserve the originality of the views. The literature was reviewed using the principles of deductive reasoning and methods of content analysis, where care was taken to use all the facts published in standard scientific journals with science citation index number. Based on the review, the manuscript has been divided in distinctly different sections as follows.

3.0 Results and Discussion

3.1 Fly ash disposal strategies

Hjelmar (1990) suggested a long-term disposal strategy for fly ash disposal, which takes into account the largely insoluble nature of pulverized coal fly ashes. Gutiérrez et al. (1993) reported that assessment of physical characteristics, chemical composition and leaching behaviour of a waste fly ash (from a coal-fired power station) should be performed prior to selection of fly ash management method. Prasad (2007) reported that forests in India offer a valid option for management of fly ash, especially in view of the excessive soil erosion.

Lima et al., (2008) concluded that each fly ash type needs to be studied separately owing to profound dissimilarity amongst all ash types. Kulkarni et al., (2008) reviewed remediation technologies available for reducing dioxins formation and emission from sources such as flue gas, Fly ash and soil. Hashim et al., (2011) reviewed thirty five approaches to suit dissimilarities and complex soil chemistry. They have broadly classified them as chemical, biochemical/biological/biosorption and physico-chemical treatment processes.

3.2 Fly ash utilization in agriculture

Alva (1994) has stated the potential of fly ash for possible widespread use for improving citrus production and combined use of fuel-gas desulfurization gypsum and fly ash. Brown et al., (1997) have indicated through their studies that the fly ashes contain numerous compounds, such as calcite ($CaCO_3$), anhydrite $CaSO_4$ and, in the Tidd fly ash, dolomite [$CaMg(CO_3)_2$], that have the potential to be a nutrient source and a soil amendment for the reclamation of acid and sodic soils (soils influenced by high levels of sodium). Based on their greenhouse study, authors demonstrated that the fly ash was an effective amendment for the remediation of acid spoil materials.

In view of the fly ash management using phytoremediation approach, Jusaitis & Pillman (1997) have reported that the soil or compost overlay provides a seed bed for initial germination away from the toxic elements of the ash, while the stabilization treatment prevented wind-blown removal of both seed and seed bed, while also conferring some protection to germinating seedlings. After such stabilization, there appears to be a greater chance for phytoremediation. Furthermore, Pillman & Jusaitis (1997) have expressed a need to comprehensively study the role of different parameters that have a role in promoting vegetation for its use in delineating strategies to manage wastes such as fly ash.

Gupta et al. (2002) have reported that fly ash has the potential to be used as an agricultural amendment in view of the chemical contents that are present in it. Authors have proposed systematic establishment of the plant species beginning with nitrogen-fixing plants that have an apparent heavy metal- tolerance followed by others. However, they further stated that more focused studies are warranted to determine the optimum use of fly ash in agricultural area. Rautaray et al., (2003) have stated that application of fly ash alone was effective in raising soil available P and integrated use of fly ash, organic wastes and chemical fertilizers was beneficial in improving overall crop yield (of rice i.e. *Oryza sativa* and their residual effect on mustard i.e. *Brassica napus var glauca*), soil pH, organic carbon and available N, P and K in sandy loam acid lateritic soil.

Mitra et al., (2005) have asserted that fly ash can be used as a potential source of soil amendment and a component of integrated plant nutrient supply system, which authors claimed to be helpful in sub-tropical climate, where high rainfall and high temperature is responsible for low soil productivity due to losses of bases and low organic matter content in soil. Furthermore, authors stated that fly ash could be applied safely to tropical agro eco-systems for retaining productivity of acid lateritic soil.

Lee et al., (2006) have reported that the application of fly ash increased Si, P and K uptake by the rice plants (*Oryza sativa*), but did not result in an excessive uptake of heavy metals in the submerged paddy soil, which indicates that fly ash could be a good supplement to other inorganic soil amendments to improve the nutrient balance in paddy soils.

Kumpiene et al., (2007) claimed that Cu and Pb mobility and bioavailability (through leaching) in soil can be lowered by the addition of coal fly ash and natural organic matter (peat), which may increase seed germination rate, reduce metal accumulation in plant shoots, and decrease toxicity to plants and bacteria.

On the basis of their studies, Singh et al., (2008) have reported that *Beta vulgaris* L. var All Green H1 plant is sensitive to fly ash concentrations and they recommended that fly ash should not be used as an amendment for leafy vegetable like *B. vulgaris*. Kishor et al. (2010) have reported that the high concentration of elements (K, Na, Zn, Ca, Mg and Fe) in fly-ash increases the yield of many agricultural crops. Furthermore, the authors advocated use of fly ash in agriculture, especially in view of its ability to minimize CO_2 emissions from agricultural activities.

Pandey & Singh (2010) stated that the higher dosage of fly ash in agriculture result in heavy metal pollution, which hinders the microbial activity. And hence, practical value of fly ash in agriculture as an "eco-friendly and economic" fertilizer or soil amendments should be established only after repeated field experiments for each type of soil to confirm its quality and safety.

Pourrut et al. (2011) claimed that *Alnus glutinosa*, *Acer pseudoplatanus* and *Robinia pseudoacacia* have a high long-term efficiency of phytostabilisation on agricultural soils highly contaminated by cadmium, lead, and zinc. Mohammadi & Rokhzadi (2012) reported that combined application of farmyard manure, compost, chemical fertilizers and fly ash elevated the nitrogen uptake rate and grain oil yield (in chickpea and sunflower). However, they also suggested use of phosphate solubilizing bacteria and *T. harzianum* for increase in nitrogen and sulfur contents of grain. Técher et al., (2012) on the basis of their investigation reported that *Miscanthus x giganteus* could be an effective strategy for cost effective and long term fly ash disposal site rehabilitation. Alva et al., (1994) reported increase in Ca, Ca &K and Ca & P in the leaves seedlings respectively on application of 2g/kg of FGD gypsum, fly ash, or chicken manure.

Salunkhe et al., (1998) studied the effect of microbiological treatment with Pseudomonas mendocina and observed increased growth in wheat seedlings. This method is potentially useful in bioremediation in chromate contaminated sites. Ottosen et al., (2007), while conducting a study on Cd reduction found that the same was possible without increasing the concentration of other heavy metals. They have reported success in their trials of electro-dialysis of wastewater sludge and bio-ashes.

Basu et al., (2009) reviewed Fly ash's great potentiality in agriculture due to its efficacy in modification of soil health and hence performance. Bioremedial studies studies based on biological transformation was carried out by Popa et al., (2010) where authors suggested utilization of lignums for crop cultivation and its potential for sequestering carbon to aid reduction in global warming.

3.3 Biotransformation of fly ash

Kapoor & Viraraghavan (1998) have reported that pretreatment of live *A. niger* biomass using sodium hydroxide, formaldehyde, dimethyl sulphoxide and detergent resulted in significant improvements in biosorption of lead, cadmium and copper in comparison with live *A. niger* cells. Pretreatment of *A. niger* reduced biosorption of nickel as compared to live cells.

Bipp et al., (1998) examined the leaching capacities of the complex agents containing solutions in a series of batch tests with a fly ash from municipal waste incineration. Authors demonstrated that sugar biomass hydrolysate, which contains sugar acids, can be used as effective agents for the remediation of heavy metals which are bound to or included in the matrix of waste incineration residues. Authors stated that this is leaching process is advantageous since sugar acids are particularly effective in the pH range which is normally measured for waste incineration residues.

Based on their study results, Petit & Rucandio (1999) stated that application of a sequential extraction scheme has high efficiency in the determination of binding forms of trace cadmium in three materials, such as coal fly ash (NBS 1633a), soil (NIST 2709) and river sediment (CRM 320). Seidel et al., (2001) have stated that *Thiobacillus thiooxidans* (*T thiooxidans*) bacteria can be used for bioleaching of aluminum and iron from coal fly ash (CFA). Authors presumed that the mechanism of extracellular polymeric substances production was related to the presence of the particulate solid phase.

Sinha & Gupta (2005) have reported that in view of its tolerance, the plants *of Sesbania cannabina Ritz* may be used for phytoremediation of metals (Fe, Mn, Zn, Cu, Pb and Ni) and suggested its application as suitable species for plantation on fly ash landfills. Maiti et al., (2005) have reported the relative abundance of bioavailable, acid extractable and total metals in fly ash in the order of: Fe> Mn> Zn> Ni > Co >Cu. The variation of biological accumulation coefficient of metals for plant (*Cynodon dactylon*) growing in the fly ash dyke was reported to be Fe>Zn> Mn >Pb>Ni >Cu > Co and Fe was the element most easily absorbed by plants.

Moreover, Gupta & Sinha (2006) reported that the plants of *Brassica juncea* grown on soil amended with 25% fly ash show a significant increase in plant biomass, plant shoot and plant height, which confirms that it (*B. juncea*) can be used for phytoextraction of metals, especially Ni in fly ash amendment soil. Kumari & Singh (2011) claimed that the translocation of metal was invariably more from root to stem than from stem to leaf which was regulated by plant (*Brassica juncea*) transport mechanism and metal mobility. They further stated that bacteria that are known to excrete protons, organic acids, enzymes and siderophores which enhance the mobilization of metals could have boosted the phytoextraction of metals from fly ash.

Brown et al., (1997) investigated whether pressurized fluidized bed combustion PFBC ash could be used as soil amendments for acid and sodic soils. The study showed that the PBFC fly ash was effective acid soil amendments. In a comparison with Ag-lime, the fly ash reacted with the soil at a slower rate and the final pH of the treated specimen was slightly lower (~7vs ~8). In addition, the EC of the fly ash treated soil was ~1mS cm^{-1} higher than that associated with Ag-lime treated samples. The authors also conducted a greenhouse study and demonstrated that fly ash was an effective amendment for the acid-spoiled soil. In fact, the soils amended with fly ash supported higher plant production than those treated with Ag-lime.

Kapoor and Viraraghavan (1998) observed the effect of pretreatment of Aspergillus niger biomass on biosorption of lead, copper, cadmium and nickel. Pretreatment of live *A. niger* biomass using sodium hydroxide, formaldehyde, dimethyl sulphoxideand detergent resulted in significant improvements in biosorption of lead, cadmium and copper in comparision with live *A. niger* cells.

3.4 Fly ash and sewage sludge

Papadimitriou et al., (2008) asserted that fly ash can be used (with sewage sludge in different ratios) to stabilize the sewage sludge. Furthermore, the authors stated that the combined use of fly ash and sewage sludge result in low phytotoxicity. Samaras et al., (2008) also reported that fly ash can be used for sewage treatment and further advocated use of this combination (fly ash and sewage sludge) as an amendment for agricultural purpose (however after evaluating its toxicity). Lin et al., (2009) elucidated the behaviour of heavy metals in slag produced from four different sewage sludge ashes mixed with municipal solid waste incinerator fly ash and then co-melted. The speciation in fly ash consisted of anhydrite, microcline, calcium chloride, sylvite and halite.

3.5 Phyto-transformation

Jamil et al., (2009) reported that *Jatropha curcas* has the potential of establishing itself on fly ash when provided with basic plant nutrients and can also accumulate heavy metals many folds from fly ash without attenuating plant growth. Yang et al., (2009) stated that the biosorption of heavy metals by biomass might occur during the bioleaching of fly ash (by *Aspergillus niger*). They concluded that though the biomass sorption occurred during the bioleaching process, it did not inhibit the removal of Al, Fe, Pb and Zn evidently from fly ash.

Sočo & Kalembkiewicz (2009) claimed that coal fly ash is a source of environmental contamination by Cr especially, in soils where its utilization is inadequate. Pandey et al., (2009) reported that there is a need to study the phytoremediation, phytomanagement and biomass production vis-à-vis fly ash in developing countries like India. Lopareva-Pohu et al., (2011) reported that phytostabilisation of metal trace element-highly contaminated soils can be achieved using metal tolerant plants (*Lolium perenne* and *Trifolium repens*) by establishing a vegetation cover in order to promote *in situ* immobilisation of trace elements.

Lopareva-Pohu et al., (2011) stated that for long-term phytostabilisation (of agricultural soils highly contaminated with trace elements), special attention should be focused on the soil pH, metal mobility and phytoavailability analysis. Kumari et al. (2011)[15] through their study results confirmed that *Pteris vittata* L. subsp. vittata is a heavy metals accumulator and that it is a highly suitable candidate for phytoremediation of metal contaminated wastelands.

Tripathi et al., (2004) grew plants of cassia siamea lamk in garden soil treated with fly ash (100%) and Fly ash amended by ameliorants (cow-dung manure, press-mud, garden soil, 1:1,w/w). Fly ash + mud press (1:1, w/w) proved to be the best combinations as growth (total biomass, number of leaves, photosynthetic area, total chlorophyll and protein) was significantly high with this treatment followed by cow dung manure and garden soil. It was reported that the metallic uptake was significantly more in plants grown in fly ash + press-mud mixture. Authors reported this might be attributed to some detoxification mechanism active in this treatment. This is an indicator that *C. siamea* seems to be a suitable plant to be grown on ash dumps.

Pavle Pavlovic et al., (2004) conducted an eco-physiological research on the fly ash deposits from " Nikola-Tesla A" thermal power station in Serbia covering 10 plant species (Tamarix gallica, populous alba, Spiraea vanhauttei, Ambrosia artemisifolia, amorpha fruticosa, Eupatorium cannabinum, Crepis setosa, Epilobium collinum, Verbascum phlomoides, Cirsium arvense). This study discussed the results of a water regime analysis, photosynthetic efficiency and trace elements (B, Cu, Mn, Zn, Pb and Cd) content in vegetative plant parts. An analysis of tissue trace elements content showed a lower trace metal concentration in plants than in ash indicating that heavy metals undergo major changes in concentration levels during the combustion process and some are not readily taken up by the plants. This point to the fact that more detailed study of factors affecting vegetation need to be assessed before choosing the types of vegetation to be grown over mounds of Fly ash.

A study was conducted by Sinha and Gupta (2005) on the tolerance of plants of Sesbania cannabina Ritz to metals(Fe, Mn, Zn, Cu, Pb and Ni)and reported possible flyash lanfills' phytoremediation with these plantations. Maiti et al., (2005) have reported that Cynodon dactylon have been observed to accumulate metals biologically (Fe>Mn.Zn>Ni> Co> Cu, preference) in abundance. Fe was found to be most easily absorbed metal of all that was present in fly ash dykes.

4.0 Conclusions

Even though the fly ash generation due to continuous use of coal for power generation has negative environmental impact, the current energy demand in India will not lower the fly ash generation in immediate future. Hence, the fly ash disposal and management has achieved a significant importance. The problem of fly ash management is especially complex because of the quantum of fly ash generation, which depends upon the quality of coal burnt and mainly the ash content of the coal. Based on the literature review it may be concluded that there are few attempts to study the fly ash management in general and treatment in particular, they appear to be focused on physical management (use in backfilling and reclamation of abandoned opencast mine voids). However, the operational difficulties for such a fly ash management initiatives as reported by Maiti et al., (2005) are the knowledge of proper contouring and drainage of the fill area, quality of topsoil (which is used as cover material), proper spreading of topsoil and advance measures for the control of gully erosion, etc. In addition to this, the physico-chemical assessment of the fly ash has also been advocated by many authors for appropriate fly ash disposal.

Furthermore, it was also observed from the literature that many attempts have been made to use different plant species with substantial/partial success for facilitating the bio-transformation of the fly ash. This transformation was studied especially in view of the agricultural use of fly ash (as an amendment or filler). Within the agriculture domain, both non commercial and commercial (vegetables and cash crops) have been studied with respect to fly ash. Besides, several studies proposed that fly ash can be used as a soil ameliorate that may improve physical, chemical and biological properties of the degraded soils and is a source of readily available plant micro- and macro-nutrients. Such a system can be used for agricultural purpose. Overall, it may be concluded from the literature review that the general studies pertaining to the fly ash management, disposal or use revolve around its use for reclamation, phytoremediation, as an eco-friendly and economic fertilizer, zeolite synthesis, etc. However, considering its availability and qualitative nature, fly ash offers a great opportunity for it being used in varied ways. Hence, further studies are warranted with a more clear focus, which can culminate in generation of mathematical models for possible use of the knowledge pertaining to fly ash management and utilization.

5.0 Acknowledgements

Authors thank University Grants Commission for financial support for this research work.

6.0 References

1. Alva, A.K., (1994). Possible utilization of fuel-gas desulfurization gypsum and fly ash for citrus production: Evaluation of crop growth response, *Waste Management*, 14(7), 621–627
2. Basu, M., Pande, M., Bhadoria, P.B.S., and Mahapatra, S.C., (2009). Potential fly-ash utilization in agriculture: A Global Review., *Progress in Natural Science*, 19(10), 1173-1186
3. Bipp, H.P., Wunsch, P., Fischer, K., Bieniek, D., and Kettrup, A., (1998) Heavy metal leaching of fly ash from waste incineration with gluconic acid and a molasses hydrolysate, *Chemosphere*, 36(11), 2523–2533

4. Brown TH., Bland A.E., and Wheeldon J.M., (1997). Pressurised Fluidised Bed combustion ash 2. Soil and mine spoil amendmentsuse options, *Fuel*, 76(8), 741-748
5. González, A., Navia, R., and Moreno, N., (2009). Fly ashes from coal and petroleum coke combustion: current and innovative potential applications, *Waste Manag Res*, 27(10), 976-987
6. Gupta AK, and Sinha S., (2006) Role of Brassica juncea (L.) Czern. (var. Vaibhav) in the phytoextraction of Ni from soil amended with fly ash: selection of extractant for metal bioavailability, *J Hazard Mater*., 136(2), 371-378.
7. Gupta, D.K., Rai, U.N., Tripathi, R.D., and Inouhe, M., (2002). Impacts of fly-ash on soil and plant responses, *Journal of Plant Research*, 115(6), 401-409.
8. Gutiérrez, B., Pazos, C., and Coca, J., (1993). Characterization and Leaching of Coal Fly Ash, *Waste Manag Res*, 11(4), 279-286
9. Hashim, M.A., Mukhopadhyay, S., Sahu, J.N., and Sengupta, B., (2011). Remediation technologies for heavy metal contaminated groundwater, *Journal of Environmental Management*, 92(10), 2355-2388
10. Hjelmar, O, (1990). Leachate from land disposal of coal fly ash, *Waste Manag Res*, 8(1), 429-449
11. Jamil, S., Abhilash, P.C., Singh, N., and Sharma, P.N., (2009). Jatropha curcas: a potential crop for phytoremediation of coal fly ash, *J Hazard Mater*. 172(1), 269-275.
12. Jusaitis, M., and Pillman, A., (1997). Revegetation of Waste Fly Ash Lagoons. I. Plant Selection and Surface Amelioration, *Waste Manag Res*, 15(3), 307-321.
13. Kapoor a., and Viraraghvan T., (1998). Biosorption of heavy metals on Aspergillus niger: Effect of pretreatment, *Bioresearch technology*, 63(2): 109-113
14. Kishor, P., Ghosh, A.K., and Kumar, D., (2010). Use of Fly ash in Agriculture: A Way to Improve Soil Fertility and its Productivity, *Asian Journal of Agricultural Research*, 4(1), 1-14
15. Kulkarni, P.S., Crespo, J.G., Alfonso, C.A.M., (2008). Dioxin sources and current remediation technologies – A review., *Environment International*., 34, 139-153
16. Kumari, A., Lal, B., Pakade, Y.B., and Chand, P., (2011). Assessment of Bioaccumulation of Heavy Metal by *Pteris Vittata* L. Growing in the Vicinity of Fly Ash, *International Journal of Phytoremediation*, 13(8), 779-787
17. Kumari, B., and Singh, S.N., (2011). Phytoremediation of metals from fly ash through bacterial augmentation, *Ecotoxicology*, 20(1), 166-76.
18. Kumpiene, J., Ore, S., Lagerkvist, A., and Maurice, C., (2007). Stabilization of Pb and Cu contaminated soil using coal fly ash and peat, *Environ Pollut*, 145(1), 365-73.
19. Lee, H., Ha, H.S., Lee, C.H., Lee, Y.B., and Kim, P.J., (2006). Fly ash effect on improving soil properties and rice productivity in Korean paddy soils. *Bioresour Technol*. 97(13), 1490-1497.
20. Lima, A.T., Ottosen, L.M., Pedersen, A.J., and Rebeiro, A.B., (2008). Characterisation of Fly ash, from bio and municipal waste., *Biomass and Bioenergy*, 32(3), 277-282
21. Lin, K.L., Huang, W.J., Chen, K.C., Chow, J.D., and Chen, H.J., (2009). Behaviour of heavy metals immobilized by co-melting treatment of sewage sludge ash and municipal solid waste incinerator flyash, *Waste Manag Res*, 27(7), 660-667.
22. Lopareva-Pohu, A, Verdin, A., Garçon, G., Lounès-Hadj Sahraoui, A., Pourrut, B., Debiane, D., Waterlot, C., Laruelle, F., Bidar, G., Douay F., and Shirali, P., (2011). Influence of fly ash aided phytostabilisation of Pb, Cd and Zn highly contaminated soils on *Lolium perenne* and *Trifolium repens* metal transfer and physiological stress, *Environmental Pollution*, 159(6), 1721–1729
23. Lopareva-Pohu, A., Pourrut, B., Waterlot, C., Garçon G., Bidar, G., Pruvot, C., Shirali, P., and Douay, F., (2011) Assessment of fly ash-aided phytostabilisation of highly contaminated soils after an 8-year field trial: part 1. Influence on soil parameters and metal extractability, *Sci Total Environ*., 409(3), 647-654.
24. Maiti, S.K., Singh, G., and Srivastava, S.B., (2005). Study of The Possibility of Utilizing Fly Ash for Back Filling and Reclamation of Opencast Mines: Plot and Field Scale Study With Chandrapura Fly Ash, Fly Ash India, New Delhi
25. Mitra , B.N., Karmakar, S., Swain, D.K., and Ghosh, B.C., (2005). Fly ash – A potential source of soil amendment and component of integrated plant nutrient supply system, *Fuel*, 84(11); 1447-1451
26. Mohammadi, K., and Rokhzadi, A., (2012). An integrated fertilization system of canola (*Brassica napus* L.) production under different crop rotations, *Industrial Crops and Products*, 37(1), 264–269
27. Ottosen, L.M., Pedersen, A.J., Hansen, H.K., and Rebeiro, A.B., (2007). Screening the possibility of removing Cadmium and other heavy metals from waste-water sludge and bio-ashes by an electro dialytic method, *Electrochimica acta*., 52(10), 3420-3426

28. Pandey, V.C., and Singh, N., (2010). Impact of fly ash incorporation in soil systems Agriculture, *Ecosystems and Environment*, 136(1–2), 16–27
29. Pandey, V.C., Abhilash, P.C., and Singh, N., (2009) The Indian perspective of utilizing fly ash in phytoremediation, phytomanagement and biomass production, *J Environ Manage*. 90(10), 2943-2958.
30. Papadimitriou, C.A., Haritou, I., Samaras, P., Zouboulis, A.I., (2008) Evaluation of leaching and ecotoxicological properties of sewage sludge-fly ash mixtures, *Environ Res*. 106(3), 340-8.
31. Pavlovic, P., Mitrovic, M., and Djurdevic, L., (2004). An ecophysiological study of plants growing on the Fly –Ash Deposits from the "Nikola Tesla-A Thermal Power Station in Serbia, *Environmental Management*, 33(5): 654-663.
32. Petit, M.D., and Rucandio, M.I., (1999). Sequential extractions for determination of cadmium distribution in coal fly ash, soil and sediment samples, *Analytica Chimica Acta*, 401(1), 283-291
33. Pillman, A., and Jusaitis, M., (1997). Revegetation of Waste Fly Ash Lagoons II. Seedling Transplants and Plant Nutrition, *Waste Manag Res*., 15(4), 359-370.
34. Pourrut, B., Lopareva-Pohu, A., Pruvot, C., Garçon G, Verdin A., Waterlot, C., Bidar, G., Shirali, P., and Douay, F., (2011). Assessment of fly ash-aided phyto-stabilisation of highly contaminated soils after an 8-year field trial Part 2. Influence on plants, *Sci Total Environ*. 409(21), 4504-10
35. Prasad, M.N.V., (2007). Phytoremediation in India, Methods in Biotechnology, 23(4), 435-454.
36. Rautaray S.K., Ghosh B.C., and Mittra B.N., (2003). Effect of fly ash, organic wastes and chemical fertilizers on yield, nutrient uptake, heavy metalcontent and residual fertility in a rice-mustard cropping sequence under acid lateritic soils, *Bioresour Technol*. 90(3), 275-283.
37. Salunkhe, P.B., Dhakephalkar, P.K., Paknikar, K.M., (1998). Bioremediation of hexavalent chromium in soil microcosms., *Biotechnology Letters*., 20(8), 749-751
38. Samaras, P., Papadimitriou, C.A., Haritou, I, and Zouboulis, AI., (2008). Investigation of sewage sludge stabilization potential by the addition of fly ash and lime, *J Hazard Mater*. 154(1-3), 1052-1059.
39. Seidel, A., Zimmels, Y., and Armon, R., (2001) Mechanism of bioleaching of coal fly ash by Thiobacillus thiooxidans, *Chemical Engineering Journal*, 83(2), 123-130.
40. Singh, A., Sharma, R.K., and Agrawal, S.B., (2008). Effects of fly ash incorporation on heavy metal accumulation, growth and yield responses of Betavulgaris plants, *Bioresource Technology*. 99(15), 7200-7207.
41. Sinha, S., and Gupta, A.K., (2005) Translocation of metals from fly ash amended soil in the plant of Sesbania cannabina L. Ritz: effect on antioxidants, *Chemosphere*. 61(8), 1204-1214.
42. Sočo, E., and Kalembkiewicz, J., (2009). Investigations on Cr mobility from coal fly ash, *Fuel*, 88(8), 1513–1519
43. Suhara H., Daikoku, C., Takata, H., Suzuki, S., Matsufuji, Y., Sakai K., and Kondo, R., (2003). Monitoring of white-rot fungus during bioremediation of polychlorinated dioxin-contaminated fly ash, *Appl Microbiol biotechnol*. 62(5-6), 601-607.
44. Techer D., Laval-Gilly, P., Bennasroune A., Henry, S., Martinez-Chois,C., D'innocenzo, M., and Falla, J., (2012). An appraisal of Miscanthus x giganteus cultivationfor fly ash cultivation and soil restoration, Industrial Crops and Products, 36(1), 427-433
45. Tripathi, R.D., Vajpayee, P., Singh, N., Rai, U.N., Kumar, A., Ali, M.B., and Yunus, M., (2004). Efficacy of various amendments for amelioration of fly-ash oxicity: Growth performance and metal composition of Cassia siamea Lamk., *Chemosphere*., 54(11), 1581-1588
46. Yang, J., Wang, Q., Luo, Q., Wang, Q., and Wu, T., (2009) Biosorption behavior of heavy metals in bioleaching process of MSWI fly ash by *Aspergillus niger*, *Biochemical Engineering Journal*, 46(3), 294–299