Recent Research in Science and Technology 2014, 6(1): 30-35
ISSN: 2076-5061
Available Online: http://recent-science.com/

Fly ash – waste management and overview : A Review

Aakash Dwivedi* and Manish Kumar Jain**

Department of Environmental Science and Engineering, Indian School of Mines, Dhanbad-814004, Jharkhand, India

Abstract

Fly ash (FA)-a coal combustion residue of thermal power plants has been regarded as a problematic solid waste all over the world. India has some of the largest reserves of coal in the world. Indian coal has high ash content and low calorific value. Nearly 73% of the country's total installed power generation capacity is thermal of which coal-based generation is 90%. Some 85 thermal power stations, besides several captive power plants use bituminous and sub-bituminous coal and produce large quantities of fly ash. High ash content (30% - 50%) coal contributes to these large volumes of fly ash. Current annual production of Fly ash, a by-product from coal based thermal power plant (TPPs), is about 112 million tones (MT). Some of the problems associated with Fly ash are large area of land required for disposal and toxicity associated with heavy metal leached to groundwater. Fly ash, being treated as waste and a source of air and water pollution till recent past, is in fact a resource material and has also proven its worth over a period of time. The present paper reviews the potential applications for coal fly ash as a raw material: as a soil amelioration agent in agriculture, use, in highway embankments, in construction of bricks, as an aggregate material in Portland cement, filling of low lying areas etc in the manufacture of glass and ceramics, in the production of zeolites, in the formation of mesoporous materials, in the synthesis of geopolymers, for use as catalysts and catalyst supports, as an adsorbent for gases and waste water processes, and for the extraction of metals. Thus fly ash management is a cause of concern for the future. This article attempts to highlight the management of fly ash to make use of this solid waste, in order to save our environment.

Keywords: Fly ash, particulate matter, thermal power plants, waste management, water pollution.

INTRODUCTION

India is the third largest producer of coal and coal based thermal power plant installations in India contribute about 70% of the total installed capacity for power generation [1]. However, the bituminous and sub-bituminous coals used contain over 40% ash content. At present, 120-150 million tons of coal fly ash is generated from 120 existing coal based thermal power plants in India [2]. Coal fly ash is an industrial waste generated from coal combustion process in thermal power plants. It is a fly ash, a coal combustion residue having a complex heterogeneous mixture of amorphous and crystalline phases and is generally fine powdered ferroaluminosilicate material with Al, Ca, Mg, Fe, Na and Si as the predominant elements. The coal fly ash also contains significant amounts of toxic metals such as As, Ba, Hg, Cr, Ni, V, Pb, Zn and Se characteristically enriched in coal fly ash particles [3-5]. The coal fly ashes occupy more space in the premises of industrial plants and are mixed with water to discharge into fly ash settling ponds or land fills. Large quantities of coal fly ashes are stored in the form of waste heaps or deposits, whose contamination poses a serious threat to the environment as a major source of inorganic pollution. The behavior of many metal pollutants and the release of such metals during storage can have deleterious effects on the environment as well as on human health [6]. Metals present in the ashes are originated from the composition of the coal used in combustion, combustion conditions, removal efficiency of air pollution control device and method of coal fly ash disposal [7].

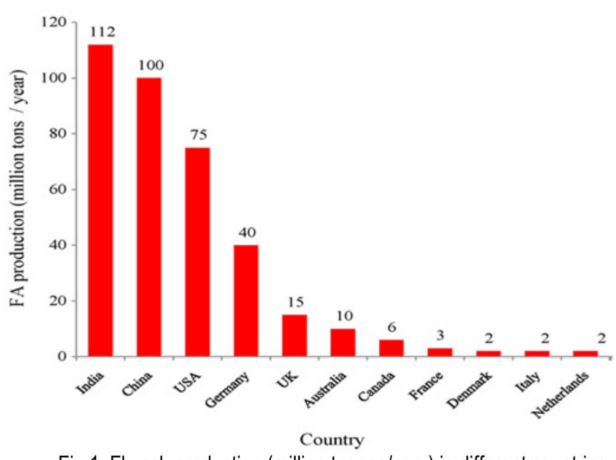

Fig 1. Fly ash production (million tonnes/year) in different countries (source: http://www.tifac.org.in)

Metals present in the ashes are originated from the compo-Large number of innovative alternate building materials and low cost construction techniques developed through intensive research efforts during last three to four decades satisfies functional as well as specification requirements of conventional materials/techniques and provide an avenue for bringing down the construction cost. Fly Ash, an industrial by-product from Thermal Power Plants (TPPs), with

*Corresponding Author
Aakash Dwivedi
Department of Environmental Science and Engineering, Indian School of Mines, Dhanbad-814004, Jharkhand, India

Email: aakashdwivedi4@gmail.com

current annual generation of approximately 112 million tones and its proven suitability for variety of applications as admixture in cement/concrete/mortar, lime pozzolana mixture (bricks/blocks) etc. Cement and Concrete Industry accounts for 50% Fly Ash utilization, the total utilization of which at present stands at 30MT (28%). The other areas of application are Low lying area fill (17%), Roads & Embankments (15%), Dyke Raising (4%), Brick manufacturing (2%) and other new areas for safe disposal of fly ash is in paint industry, agriculture etc [8].

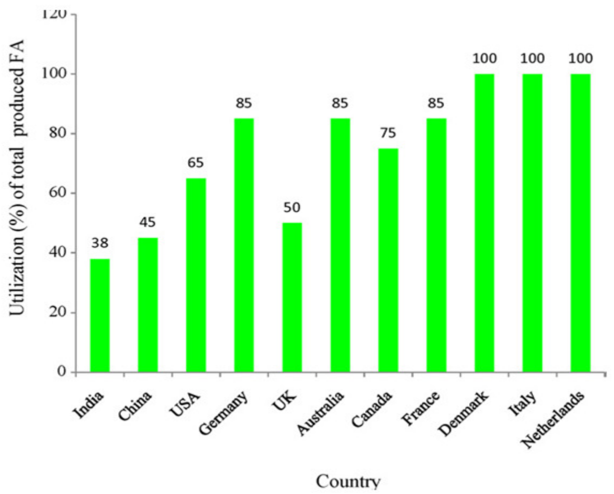

Fig 2. Utilization (%) of total produced fly ash in different countries (Source: http://www.tifac.org.in)

Effluent and disposal

Disposal and management of fly ash is a major problem in coal-fired thermal power plants. Fly ash emissions from a variety of coal combustion units show a wide range of composition. All elements below atomic number 92 are present in coal ash. A 500 MW thermal power plant releases 200 mt SO2, 70 t NO2 and 500 t fly ash approximately every day. Particulate matter (PM) considered as a source of air pollution constitutes fly ash. The fine particles of fly ash reach the pulmonary region of the lungs and remain there for long periods of time; they behave like cumulative poisons. The submicron particles enter deeper into the lungs and are deposited on the alveolar walls where the metals could be transferred to the blood plasma across the cell membrane (fig. 1). The residual particles being silica (40–73%) cause silicosis. All the heavy metals (Ni, Cd, Sb, As, Cr, Pb, etc.) generally found in fly ash are toxic in nature [9]. Fly ash can be disposed-off in a dry or wet state. Studies show that wet disposal of this waste does not protect the environment from migration of metal into the soil. Heavy metals cannot be degraded biologically into harmless products like other organic waste. Studies also show that coal ash satisfies the criteria for landfill disposal, according to the Environmental Agency of Japan. According to the hazardous waste management and handling rule of 1989, fly ash is considered as non-hazardous. With the present practice of fly-ash disposal in ash ponds (generally in the form of slurry), the total land required for ash disposal would be about 82,200 ha by the year 2020 at an estimated 0.6 ha per MW. Fly ash can be treated as a by-product rather than waste [10].

Laws and Legislation of Disposal of Flyash

Historically, wastes have always created a disposal problem. The problem of flyash disposal has assumed such an enormous scale in the country that the Ministry of Environment and Forests (MoEF) issued a regulation on 14 September 1999 specifying normative levels for progressive utilization of flyash. According to the regulation, it is mandatory for the existing (old) and new coal based thermal power plants to utilize 100% of the flyash produced in a stipulated time horizon. The new coal thermal power plants are required to use 100% of the flyash produced within nine years of commencing operation. The old power plants, however, are required to achieve 100% flyash utilization goal with in 15 years from the date of issue of the regulation [11].

Table 1. Thermal power generation, coal consumption and ash generation in India (Source: Current Sc 1792 IENCE Vol. 100,No. 12, 25 June 2011)

1995	54,000	200	75
2000	70,000	250	90
2010	98,000	300	110
2020	137,000	350	140

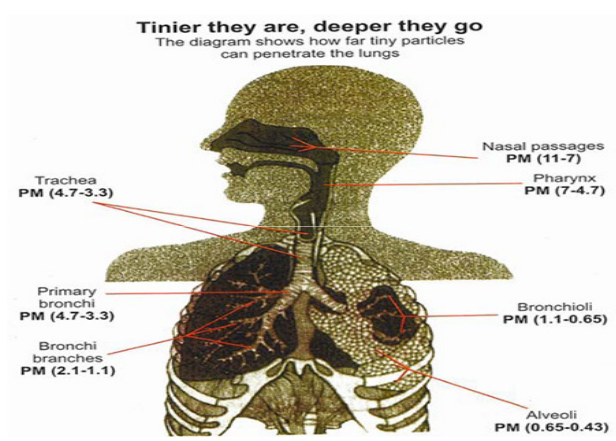

Fig 3. Penetration of tiny particles into the lungs.(Source:- Current Sc 1792 IENCE Vol. 100,No. 12, 25 June 2011)

Classification of fly ash

Fly ash particles are generally spherical in shape and range in size from 0.5 µm to 100 µm. They consist mostly of silicon dioxide (SiO_2), which is present in two forms: amorphous, which is rounded and smooth, and crystalline, which is sharp, pointed and hazardous; aluminum oxide (Al_2O_3) and iron oxide (Fe_2O_3). Fly ashes are generally highly heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite, and various iron oxides.

Two classes of fly ash are defined by ASTM C618: Class F fly ash and Class C fly ash. The chief difference between these classes is the amount of calcium, silica, alumina, and iron content in the ash. The chemical properties of the fly ash are largely influenced by the chemical content of the coal burned (i.e., anthracite, bituminous, and lignite) [13].

Class C fly ash

Fly ash produced from the burning of younger lignite or sub bituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties. In the presence of water, Class C fly ash will harden and gain strength over time. Class C fly ash generally contains more than 20% lime (CaO). Unlike Class F, self-cementing Class C fly ash does not require an activator. Alkali and sulfate (SO_4) contents are generally higher in Class C fly ashes [12].

Class F fly ash

The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash. This fly ash is pozzolanic in nature, and contains less than 10% lime (CaO). Possessing pozzolanic properties, the glassy silica and alumina of Class F fly ash requires a cementing agent, such as Portland cement, quicklime, or hydrated lime, with the presence of water in order to react and produce cementitious compounds. Alternatively, the addition of a chemical activator such as sodium silicate (water glass) to a Class F ash can lead to the formation of a geopolymer [12].

Fig 4. Typical ash colors (Class „F" & „C" Fly ash)
(Source:- International journal of emerging trands in Engineering and Development Issue1, Vol 1August2011)

Fly ash utilization

During the last 30 years, extensive research has been carried out to utilize the fly ash in various sectors, as this is not considered as hazardous waste. Broadly, fly ash utilization programmes can be viewed from two angles, i.e. mitigating environmental effects and addressing disposal problems (low value–high volume utilization) [9]. Following are some of the potential areas of use of fly ash:-

Development of Fly Ash Based Polymer Composites as Wood Substitute

Fly ash based composites have been developed using fly ash as filler and jute cloth as reinforcement. The technology on fly ash Polymer Composite using Jute cloth as reinforcement for wood substitute material can be applied in many applications like door shutters, partition panels, flooring tiles, wall panelling, ceiling, etc. This technology has been developed by Regional Research Laboratory, Bhopal in collaboration with Building Materials & Technology Promotion Council (BMTPC) and TIFAC. One commercial plant has also been set up based on this technology near Chennai [13].

Fly Ash Based Cement

As per the specifications of Bureau of Indian Standards fly ash upto 35% can be used in manufacture of PPC, while worldwide there are examples of countries that permit upto 55% utilisation of fly ash in PPC production. Setting aside 25% of cement production for OPC for such applications, the balance 75% can be PPC with an average fly ash content of 30% [14]. It would consume around 25 MT fly ash, replacing same amount of cement clinker and resulting in net saving Rs. 2500 crore [15].

Role of bio-amelioration of FA on soil

Recent investigations suggest that FA can find better application if combined with organic amendments such as cow manure,press mud, paper factory sludge, farmyard manure, sewage sludge,crop residues and organic compost for improvement of degraded/marginal soil [16]. Few beneficial combined effects of FA and organic matter on soil have been found such as reduced heavy-metal availability and killing pathogens in the sludge [17]; improved soils through higher nutrient concentrations,better texture,lower bulk density, higher porosity and mass moisture content and higher content of fine-grained minerals [18]; enhanced the biological activity in the soil [19]; reduced the leaching of major nutrients [20]; and beneficial for vegetation [21]; .Use of swine manure with FA increased the availability of Ca and Mg balancing the ratio between monovalent and bivalent cations (Na^{++} K^{+}/Ca^{2+} Mg^{2+}), which otherwise proves detrimental to the soil [22]; Co-utilization of 'slash' a mixture of FA, sewage sludge and lime in the ratio of 60:30:10 had beneficial soil ameliorating effect. 'Slash' incorporation in soil showed positive effects on soil pH and Ca, Mg and P content and reduction in the translocation of Ni and Cd [23] and enhanced growth and yield of corn, potatoes and beans in pot trials. So, amendment with FA will enhance agricultural sector for crop production. Further, organic amendment application will provided anchorage and growth of the plant on a FA dumping site [24].

Fly ash bricks

The Central Fuel Research Institute, Dhanbad has developed a technology for the utilization of fly ash for the manufacture of building bricks [9]. Fly Ash can be used in the range of 40-70%. Our current clay brick production exceeds 100 billion bricks a year. In such circumstances and when fly ash brick is technically acceptable, economically viable and environment friendly, it may not be wrong to target to produce at least 2 billion fly ash bricks per year. It would consume about 5 million tonne of flyash/year, yielding a net saving of around Rs. 20 crores per annum. Fly ash bricks have a number of advantages over the conventional burnt clay bricks. Unglazed tiles for use on footpaths can also be made from it. Awareness among the public is required and the Government has to provide special incentives for this purpose [21].

Fly ash in distemper

Distemper manufactured with fly ash as a replacement for white cement has been used in several buildings in Neyveli, Tamil Nadu, in the interior surfaces and the performance is satisfactory. The cost of production will only be 50% that of commercial distemper [9].

Fly ash-based ceramics

The National Metallurgical Laboratory, Jamshedpur has developed a process to produce ceramics from fly ash having superior resistance to abrasion [9].

Ready mixed Fly ash concrete

Though Ready Mix concrete is quite popular in developed countries but in India it consumes less than 5 percent of total cement consumption. Only recently its application has started growing at a fast rate. On an average 20% Fly ash (of cementitious material) in the country is being used which can easily go very high. In ready mix concrete various ingredients and quality parameters are strictly maintained/controlled which is not possible in the concrete produced at site and hence it can accommodate still higher quantity of fly ash [25].

Minefills

Nearly one third of our thermal power stations are at or near to pit heads. Most of these mines cart sand for backfilling from river beds, which are normally 50-80 kms away. Apart from the royalty, huge amount of expenditure is incurred on transportation of sand. It is estimated that about 15-20 million tonne of ash per annum can be safely consumed in minefills yielding a saving of about Rs. 150 crore a year [14].

Fly Ash in Road Construction

Fly ash can be used for construction of road and embankment. Saves top soil which otherwise is conventionally used, avoids creation of low lying areas (by excavation of soil to be used for construction of embankments) [8]. Fly Ash may be used in road construction for: Stabilizing and constructing sub-base or base; upper layers of pavements; filling purposes. Concrete with Fly Ash (10-20% by wt) is cost effective and improves performance of rigid pavement; Soil mixed with Fly Ash and lime increases California Bearing Ratio (CBR), increased (84.6%) on addition of only Fly Ash to soil. National Highway Authority of India (NHAI) is currently using 60 lakh m^3 of Fly Ash and pr oposed to use another 67 lakh m^3 in future projects.

Embankment

Fly ash properties are somewhat unique as an engineering material. Unlike typical soils used for embankment construction, fly ash has a large uniformity coefficient consisting of clay-sized particles. Engineering properties that will affect fly ash use in embankments include grain size distribution, compaction characteristics, shear strength, compressibility, permeability, and frost susceptibility. Nearly all fly ash used in embankments are Class F fly ashes [9]

In view of the growing need for development of road infrastructure in the country, conservative estimates show that about 15-20 MT ash can be used in construction of road and flyover embankments per annum in the vicinity of TPPs. This would yield a saving of around Rs. 100 crore per year [16].

Roller compacted concrete

Another application of using fly ash is in roller compacted concrete dams. Many dams in the US have been constructed with high fly ash contents. Fly ash lowers the heat of hydration allowing thicker placements to occur. Data for these can be found at the US Bureau of Reclamation. This has also been demonstrated in the Ghatghar Dam Project in India [14].

Asphalt concrete

Asphalt concrete is a composite material consisting of an asphalt binder and mineral aggregate. Both Class F and Class C fly ash can typically be used as a mineral filler to fill the voids and provide contact points between larger aggregate particles in asphalt concrete mixes. This application is used in conjunction or as a replacement for, other binders (such as Portland cement or hydrated lime) [14]. For use in asphalt pavement, the fly ash must meet mineral filler specifications outlined in ASTM D242. The hydrophobic nature of fly ash gives pavements better resistance to stripping. Fly ash has also been shown to increase the stiffness of the asphalt matrix, improving rutting resistance and increasing mix durability [8].

Use of Fly Ash in Agriculture

Agriculture and waste land management have emerged as prime bulk utilization areas for fly ash in the country. It improves permeability status of soil; improves fertility status of soil (soil health)/ crop yield; improves soil texture; reduces bulk density of soil; improves water holding capacity/porosity; optimizes pH value; improves soil aeration; reduces crust formation provides micro nutrients like Fe, Zn, Cu, Mo, B, Mn; provides macro nutrients like K, P, Ca, Mg, S etc; works as a part substitute of gypsum for reclamation of saline alkali soil and lime For reclamation of acidic soils; ash ponds provides suitable conditions and essential nutrients for plant growth, helps improve the economic condition of local inhabitants; crops grown on fly ash amended soil are safe for human consumption & groundwater quality is not affected [8].

Use of fly ash in agriculture has also proved to be economically rewarding. The improvement in yield has been recorded with fly ash doses varying from 20 tonne/hectare to 100 tonne/hectare. On an average 20-30% yield increase has been observed Out of 150 million hectare of land under cultivation, 10 million hectares of land can safely be taken up for application of fly ash per year. Taking a moderate fly ash dose of 20 mt per hectare it would consume 200 million tonne flyash per year. This is more than the annual availability of fly ash, therefore the shortfalls would be met from accumulated 1500 million tonne stock of fly ash (available in ash ponds). The fly ash treated fields would give additional yield of 5 million tonne foodgrains per year valued at about Rs. 3000 crore [15].

Table 2. Economic benefits of fly ash management

S.No.	Utilisation	Fly Ash Consumption (Million tonnes/year)	Savings per year (rupees in crore)
1	Cements	25	2500
2	Roads and Embankments	15-20	100
3	Minefills	15-20	150
4	Bricks	5	20
5	Agriculture	200	3000
	Total		5770 around 1.2billion US$

CONCLUSION

It has been recognized worldwide that the utilization of an enormous amount of fossil fuels has created various adverse effects on the environment, including acid rain and global warming. An increase in the average global temperature of approximately 0.56 K has been measured over the past century (global warming). Gases with three or more atoms that have higher heat capacities than those of O_2 and N_2 cause the greenhouse effect. Carbon dioxide (CO_2) is a main greenhouse gas associated with global climate change. The disposal, management and proper utilization of waste products has become a concern for the scientists and environmentalists. Proper management of solid-waste fly ash from thermal power plants is necessary to safeguard our environment. Because of high cost involved in road transportation for the dumping of fly ash, it is advisable to explore all its possible applications. Fly ash is a potential source of pollution not only for the atmosphere but also for the other components of the environment. Deposition in storage places can have negative influences on water and soil because of their granulometric and mineral composition as well morphology and filtration properties. This waste has found application in domestic and wastewater treatment, purification, paint and enamel manufacturing. In future, large-scale application of this waste product may be possible for recovery of heavy metals, reclamation of wasteland, and floriculture. The detailed investigations carried out on fly ash elsewhere as well as at the Indian Institute of Science show that fly ash has good potential for use in highway applications. Its low specific gravity, freely draining nature, ease of compaction, insensitiveness to changes in moisture content, good frictional properties, etc. can be gainfully exploited in the construction of embankments, roads, reclamation of low-lying areas, fill behind retaining structures, etc.

On the other hand it can safely be concluded that fly ash, which till recent years has been treated as a waste product of thermal power stations, is in fact a valuable resource material.

REFERENCES

[1] Sahu, S. K., Bhangare, R.C., Ajmal, P.Y., Sharma, S., Pandit, G.G., and Puranil, V.D., 2009 , Characterization and quantification of persistent organic pollutants in fly ash from coal fueled thermal power stations in India., Journal of Microchemical, 92, 92-96.

[2] Lokeshappa, B., and Dikshit, A.K., 2011, Disposal and management of coal fly ash, Proc. ICLST, 11-14

[3] Adriano, D. C., Page, A. L., Elseewi, A. A., Chang A. C., and Straughan, I., 1980, Utilization and disposal of fly ash and other coal residues in terrestrial ecosystems: a, review., Journal of Environmental Quality, 9, 333–344.

[4] Aitken, R.L., and Bell, L.C., 1985, Plant uptake and phyto-toxicity of boron in Australian fly ash., Journal of Plant and Soil, 84, 245-257.

[5] Mattigod, S. V., Rai, D., Eary, L. E., and Ainsworth, C. C., 1990, Geochemical factors controlling the mobilization of inorganic constituents from fossil fuel combustion residues: review of the major elements., Journal Environmental Qual-ity,19, 188–201.

[6] Yuan, C. C., Fang, W. C., Mui, D.T., and Chiang., H.L., 2009, Application of methods (sequential extraction procedures and high pressure digestion method) to fly ash particles to determine the elements: a case study of BCR 176., Journal of Hazardous Materials, 163, 578-587.

[7] Carlson, C. L., and Andriano, D. C., 1993, Environmental impacts of coal combustion residues, Journal of Environmental Quality., 22, 227-247.

[8] Alami, J. and Akhtar, M. N., 2011 "Fly Ash Utilisation in Different Sectors in Indian Scenario", International journal of emerging trends in Engineering and Development on Issue1, Vol 1.

[9] Senapati, M. R., 2011, "Fly ash from thermal power plants – waste management and overvi- ew", Current Sc 1792 IENCE, Vol. 100, No. 12, 25.

[10] Matani, A. G., 1998, *Res. J. Chem. Environ*., 2.

[11] Behera, R. K., 2009-10, "Charaterisation of fly ash for their effective management and utilization", from the thesis submitted in NIT Rourkela.

[12] Das, A., 2009, "Strength Characterisation of fly ash composite material", from the thesis submitted in NIT Rourkela.

[13] Saxena, M., and Prabhakar, J., 2000, "Emerging Technologies for Third Millennium on Wood Substitute and Paint from coal ash" 2nd International conference on "Fly Ash Disposal & Utilization", New Delhi, India, February.

[14] Kumar, V., Mathur, M., Sharma, P., 1999, 'Fly Ash Disposal: Mission beyond 2000 A. D., Fly Ash disposal and deposition: beyond 2000 A.D. Narosa Publishing House.

[15] Kumar, V., Mathur, M., Sharma, P., "Fly ash: A billion dollar resorce –wasted so far",

[16] Tripathi, R.D., Singh, S.N., Singh, N., Vajpayee, P., Kumar, A., 2000, Reclamation of fly ash land fills by successive plantation, soil amendments and/or through biotechnological approach. Final Technical Report. Directorate of Environment, U.P., India (unpublished material).

[17] Wong, J. W. C., 1995, The production of artificial soil mix from coal fly ash and sewage sludge. Environ. Technol. 16, 741–751.

[18] Shen, J.F., Zhou, X.W., Sun, D.S., Fang, J.G., Liu, Z.J., Li, Z., 2008, Soil improvement with coal ash and sewage sludge: a field experiment. Environ. Geol. 53, 1777–1785.

[19] Kumpiene, J., Lagerkvist, A., Maurice, C., 2007, Stabilization of Pb and Cu contaminated soil using coal fly ash and peat. Environ. Pollut. 145, 365–373.

[20] Sajwan, K.S., Paramasivam, S., Alva, A.K., Adriano, D.C., Hooda, P.S., 2003. Assessing the feasibility of land application of fly ash, sewage sludge and their mixtures.Adv. Environ. Res. 8, 77–91.

[21] Rautaray, S.K., Ghosh, B.C., Mittra, B.N., 2003, Effect of fly ash, organic wastes and chemical fertilizers on yield, nutrient uptake, heavy metal content and residual fertility in a rice–mustard cropping sequence under acid lateritic soils. Bioresour.Technol. 90, 275–283.

[22] Giardini, L., 1991, Aspetti agronomici della gestione dei reflui zootecnici. Rivista diIngegnaria Agraria 12, 679–689.

[23] Rethman, N.F.G., Truter, W.F., 2001, Plant responses on soils ameliorated with waste products. In: 16th National Meeting of ASSMR, Albuquerque, NM, USA, p. 425

[24] Pandey, V. C., and Singh, N., 2010, Impact of fly ash incorporation in soil systems. Agriculture, Ecosystems and Environment 136, 16–27.

[25] Saxena, M., and Prabhakar, J., 2000, "Emerging Technologies for Third Millennium on Wood Substitute and Paint from coal ash" 2nd International conference on "Fly Ash Disposal & Utilization", New Delhi, India, February.