Available online at www.pelagiaresearchlibrary.com

Pelagia Research Library

Advances in Applied Science Research, 2017, 8(3):32-50

ISSN : 0976-8610
CODEN (USA): AASRFC

Flyash: Characteristics, Problems and Possible Utilization

Rupnarayan Sett*

Tropical Forest Research Institute (ICFRE, MoEFCC), Mandla Road, Jabalpur, Madhya Pradesh, India

ABSTRACT

Flyash, the after-burnt tiny coal dust is a byproduct from the thermal power plants, is a alumino-silicate non-reactive inert particle which may remain suspended in the air from few seconds to several months. Till now, the major source of power in India comes from burning of low-quality coal, and the country needs more power every day. In this situation, the evaluation of this ecologically sensitive toxic substance has been assessed in this article in terms of its origin, nature, properties, environmental distribution, impact and possible biological and non-biological utilization-modes to draw the deep attention of the environment research explorers.

Keywords: Flyash, Environmental impact, Flyash disposal, Flyash legislation, Biological reclamation

INTRODUCTION

Flyash is a light coal dust coming out with the gases of coal-fired boilers. The particle size of flyash varies from one sub-micron to several micrometers and mineral admixture, inert material and good Pozzolanic properties [1]. In India, electricity is the main source of power for industries. For enormous reserve of coal in the country, coal-based power generation is the major source of energy, and the coal-generated thermal power stations have been established throughout the country. The need and consumption of power is increasing by leaps and bounds; in 1991 the total installed capacity of all the thermal power stations was 45,000 MW, in 1995 it went up to 54,622 MW, in 2003 it has reached 1,06,245 MW (NTPC Publication, 2003). About 62% of the coal produced in India is utilized for generation of 65% of total electricity. The huge burning of low quality Indian coal results into generation of various byproducts like bottom ash, boiler slag and flyash. Ash is the waste product left after the burning of many combustible substances and "flyash" is the term defined for the finely divided residues those results from the combustion of the ground coal. It is dissipated by fuel gas and wind if not checked by devices like electrostatic precipitators. Primarily the flyash particles consist of Silica and Alumina; carbon and oxides of iron, calcium, magnesium, sulfur, titanium etc. being the secondary ingredients. The location of the energy source, nature of fuel and size of the furnace determine the exact nature and quantity of these compounds. The fine particles may remain suspended in the air from few seconds to several months. The particle size distribution of the particulate matter influences residence time and transfer efficiency [2].

Flyash, the after-burnt tiny coal dust is a byproduct of the thermal power plants, property of which is dependent on the nature of the coal. The primary effect of flyash production is the generation of a number of problems, mainly because of its minute size, non-reactive nature, presence of toxic elements and huge production. With the rise of need of more and more power, the production-amount of flyash has no immediate chance of decline until the alternate power-generation methods are formulated and brought to function. The 'flyash mission' aims at innovation of various biological and non-biological utilization procedures, which encompasses a spectrum of workers from road research engineers to forest research scientists. The effect of flyash in ecosystems, especially on the plants, has drawn up deep attention of the environmentalists during the last few decades.

PROBLEMS OF FLYASH

- Flyash cannot be disposed-off in the open field because it pollutes the air, soil and ground water.

- Transportation of flyash is difficult since the lightweight particles tend to fly causing air pollution.
- Long inhalation causes serious respiratory problems.
- Affects horticulture, agriculture and forest fields.
- Disposal in sea, river or ponds damage the aquatic life; flyash causes siltation problems.
- Long and continuous use of flyash as fertilizer makes hardpan underground.
- Requirement of huge land for making ash ponds or dikes.

The most vital question of enormous importance on flyash to date is its disposal. Mostly the flyash is disposed-off in the ash pond, but there is always tremendous pressure to find the additional area for its disposal. For all the power plant management departments, flyash handling and disposal methods have been the key area of study. The massive expansion of the thermal power generation program from coal has the potential to severely interfere with the natural environment through deforestation, population displacement and discharge of solid wastes, effluents and gaseous emissions unless adequate measures are taken to keep the pollution levels within the minimum threshold limits [3].

A thumb rule calculation states that 0.68 hectare land is needed per megawatt of installed capacity for a 10 m deep ash pond that should last at least 25 years. Therefore, a large area is required for setting the ash ponds; this generates not only a source of pollution but becomes fully unproductive too [4]. The already existing ash ponds need immediate attention for checking the disposal of the contaminants. Partial greening by vegetative cover may considerably reduce such potential damage [5].

The modes of ash disposal determine its form and impact; perhaps the most negative activity of the Indian Thermal Power Plants is the huge production of flyash. The conventional method of its disposal is to transfer it as slurry to the ash ponds. From 2000, more than 9 crore tones of ash are being produced every year in India. For the year 2014 shows India produced 112 million ton of flyash, which was the highest in the world [6]; the Central Electricity Authority of India has claimed that the utilization of fly ash has increased from 6.64 million-ton in 1996-1997 to 102.54 million ton in 2014-2015.

There are two basic modes of ash disposal, viz. disposal in slurry form and disposal in dry/conditioned form. The conventional slurry disposal system requires simple ash water mixing devices near the various ash collection zones and a system of sluiceways/pipelines for carrying the resultant slurry to an in-plant pumping station. At the pumping stations, the slurry is pumped to the disposal area where the ash is stored.

The dry disposal system calls for relatively complex dry/conditioned ash handling system within the plant and in the disposal area. The system envisages making conditioned/dewatered ash available at an intermediate storage point in the plant area for transportation to the disposal area by means of belt conveyors. At the disposal area, ash is stacked and shaped to predetermined levels there by resulting in the formation of an ash mound that will ultimately reach a height of 55 m over the life of the power plant. This scheme comprises the following three distinct subsystems [7].

Plant ash extraction, conveyance and storage system

This system consists of a bottom ash handling process and a flyash handling process. The furnace bottom ash and economizer ash is conveyed to dewatering whereas the flyash is conveyed to storage soils. Water used for bottom ash handling is re-circulated from the dewatering bins. For effective down-stream handling, flyash from the storage sails is to be optimally conditioned; for this purpose, silo-unloading outlets are provided with flyash conditioners, which can add up to 20%, water to the ash.

Conditioned ash transportation system

Dewatered bottom ash and conditioned flyash are unloaded using feeder conveyors that are reversible conveyors to enable loading into trucks should it be required for sale purpose. The feeder conveyers normally discharge the ashes onto a set of belt conveyors for transportation to the disposal area.

Ash disposal area system

In the disposal area, the belt conveyors can carry the ash to any one of the three different destinations, viz. the main stockyard, the temporary stockyard and the emergency stockyard. The bottom ash and flyash are stacked separately since bottom ash is required as drainage blanket at the base of the mound. After deposition by the boom spreader in the main stockyard, mobile equipment will be employed to spread out and roll the ash. Bulldozers would be used to spread and level the ash deposited by the boom spreader. When a sufficient area of the formation bench is available, a roller would be employed to firm up the surface and increase the resistance of ash to dust blow.

USES OF FLYASH

Fly ash is generally stored at coal power plants or placed in landfills. About 43% is recycled, often used as a Pozzolan to produce hydraulic cement or hydraulic plaster and a replacement or partial replacement for Portland cement in concrete production. How it is used in India has not been fully explored yet.

Fly ash is used as a supplementary cementitious material (SCM) in the production of Portland cement concrete. A supplementary cementitious material, when used in conjunction with Portland cement, contributes to the properties of the hardened concrete through hydraulic or Pozzolanic activity or both.

Ash disposal, its utilization and the environmental concerns have been major issues and challenges to the scientists of different parts of the world. The area of research on flyash recycling is to be intensified. It is already used in manufacture of cement as a filler material, concrete, ceramics, construction fills road base and mineral filler in asphalt mix. Filling of empty mines and land filling is another promising of disposal of this waste. Another possibility might be the spreading of flyash in forestry and agricultural lands as a soil stabilizer. Because of presence of several natural elements and being alkaline, application of flyash on lands has a marked effect on physico-chemical properties of soil from the point of view of crop production.

The limiting factors in flyash utilization on land are changes in the chemical equilibrium of soil affecting its pH, salinity, levels of certain toxic elements etc. As a result of hydrolysis of calcium and magnesium oxides in ash, pH of soil increases. Researchers have shown that by application of flyash to soil at the rate of 80% by weight, pH of calcareous soil was increased from 8.0 to 10.8 and that of acidic soil increased from 5.4 to 10.0. But flyash application is not recommended for reclamation of acid soils, because by reducing acidity it causes deficiency of nutrients like phosphorus, zinc and copper while increasing levels of the trace elements viz. molybdenum, selenium and boron, which in turn become toxic to plant bodies.

In spite of these drawbacks there are reports of increase in growth and biomass production of some plant species like *Albizia procera*, Eucalyptus hybrid and increase in dry matter yields of crops like Alfalfa, wheat and paddy grown on flyash amended soils. But the increase in yield is primarily due to increased availability of the essential plant nutrients. Concentration of sulfur, molybdenum and boron in plant tissues has also been shown to increase consistently with ash application to soil. Even concentrations of non-essential trace elements like aluminium, selenium, arsenic, barium, vanadium etc. are consistently increased in plant tissues with ash application [8]. However, coal ash used in conjunction with high carbonaceous materials such as sewage sludge, plant and animal manures can be safe for land use [9].

THE FLYASH MISSION

Flyash has a good potential for being utilized the in agriculture fields in the following manner:

- As a soil amendment to modify the pH of the soil.
- As a soil conditioner to improve the physical and chemical properties of soil.
- As a source of essential plant nutrients like P, K, Ca, Mg, Cu, Zn, Fe, Mn, etc.

The physical, chemical and mineralogical properties of most of the common soil types and flyash are more or less similar in many respects. In fact, flyash is superior in some respect with regard to its high water holding capacity (WHC) and low bulk density. NTPC has got conducted studies at Rihand and Farakka Power Stations through Regional Research Laboratory (RRL), Bhopal, and the Central Fuel Research Institute (CFRI), Dhanbad, respectively in the area of flyash use in agriculture. Various cereal crops like paddy, wheat, maize, pulses like pigeon pea, chick pea, etc., vegetables like tomato, potato, brinjal, pea and commercial grasses like berseem, medicinal and aromatic plants were tested. Depending upon the soil type and its characteristics, flyash up to 560 ton/hectare can be used in agriculture/soil amendment. The above crops have been grown in ash admixed soils at various proportions and the yields of various crops have shown a considerable increase.

Similar studies have also been conducted by CFRI, Dhanbad at NTPC Ramagundam (A.P.) by the RRL, Bhopal at Madhya Pradesh Electricity Board (MPEB), Sarni (M.P.) and Captive Power Plant, National Aluminum Company (NALCO), Angul, (Orissa). Since this involves the use of flyash in a sensitive area involving food chain, follow up studies at the above sites are conducted under the supervision and control of the Indian Council of Agricultural Research (ICAR) under the aegis of the Flyash Mission (FAM) of the Government of India. Flyash mission has taken up a comprehensive study/demonstration program covering about 55 sites spread all over the country in different agro-climatic conditions under 15 technology demonstration projects [10]. The data are being generated, collected and monitored regularly by the expert teams drawing members from various institutes viz. ICAR, ICMR, CSIR, DAE, Agricultural Universities etc. Various extension activities like "Kisan Melas", "Farmers Get-Together Meets", Awareness Campaigns", etc. have motivated the farming community for the use of flyash in the agricultural fields. The positive outcome of these results is expected to encourage large-scale use of flyash in agriculture.

LEGISLATION OF FLYASH

As per the Gazette of India, Extraordinary, Part II, Section 3, Subsection (II), Ministry of Environment and Forests Notification, New Delhi, 14th September 1999, under the environment protection act, 1986 and EP rules 1986, the salient features of notifications are as follows:

- Use of flyash, bottom ash or pond ash in the manufacture of bricks and other construction activities in the locality has been defined.
- Utilization of ash by thermal power plants to be ensured.
- Specifications for use of ash-based products have been defined.

The same notification was again revised on 27th August 2003, where the main features are as follows:

- Every construction agency engaged in the construction of buildings within a radius of 50 to 100 km from a coal or lignite based thermal power plant shall use flyash bricks, blocks, tiles, clay flyash bricks.
- Bricks, cement flyash bricks or similar products or a combination or aggregate of them in such construction as per the following minimum percentage (by volume) of the total bricks, blocks and tiles, as the case may be, used in each construction project, namely: 25% by 31st August 2004, 50% by 31st August 2005, 75% by 31st August 2006 and 100% by 31st August 2007.
- In respect of construction of buildings within a radius of 50 km from a coal or lignite based thermal plant the following minimum percentage (by volume) of use of bricks, blocks and tiles shall apply:
- 50% by 31st August 2004, 100% by 31st August 2005.
- No agency, person or organization shall within a radius of 100 km of a coal or lignite based thermal power plant allow reclamation and compaction of low-lying areas with soil.

The thermal power plants have to ensure availability of fair quantity of ash to each user including brick kilns [1].

CHARACTERIZATION OF FLYASH

There are flurry of papers on the effect of flyash on soil-plant relationship focusing mainly on the utilization aspect of this power plant waste. Field and green house studies both indicate that many chemical constituents of flyash may benefit plant growth and can improve agronomic properties of soil [11]. Because most of the natural elements are present in coal ash in trace amount, addition of flyash changes physical properties, mineral composition and chemical equilibrium of the soil. The interaction between plants and flyash-amended soils are also complicated by varying edaphic factors and plant species [12].

The physical and physico-chemical properties of flyash are quite variable as they are influenced by coal source, particle size type of coal burning process and degree of weathering. Rees and Sidrak [13] observed that the major matrix elements in flyash are Si, Al and Fe with significant percentages of Ca, K, Na and Ti; flyash contains high concentrations of alkaline elements (4.48% CaO, 2.67% MgO) and increases the pH of soil to which it was added. This increase was beneficial on acid soils and was temporary; in alkaline soil, in which CO_2 was evolved soon reacted with CaO of flyash to produce $CaCO_3$ shifting the pH towards neutrality. Due to comparatively medium silica content, i.e., 41.60% and fineness of the material, flyash undergoes rapid weathering. During combustion of coal, the material is produced containing all the mineral constituents of coal, but with a very low cation exchange capacity (3 meg/100 g). Many metal oxides are embedded in the glassy phase of the flyash and might be released over a period of time. They concluded that although the range of possible crops was limited during the first few years of the life of a flyash tip, a considerably wider range of crops might be used as ash weathers.

Abernathy [14] studied trace element composition of flyash of Eastern and Midwestern coal deposits and ashes from western states. He found that western coal (lignite and sub-bituminous) flyash had higher B content but were lower in other trace elements such as As, Cd, Co, Cr, Pb, Sb and Zn. Martens et al. [15] reported the availability of K and Mo, B and Zn to plant in several flyash from Eastern and Midwestern U.S. coal sources. Doran and Martens [16] evaluated nutrient contents in flyash; they showed that elemental composition of flyash could vary widely, and ashes contained higher concentration of essential plant nutrients like Ca, K, Mo, Zn and B (except low content of available N), were available to the plant bodies.

Natuch et al. [17] reported that the mean particle density for a Midwestern U.S. flyash was 2.7 g/cm^3 for non-magnetic and 3.4 g/cm^3 for magnetic particles. They also reported that flyash collected from western states had higher B content but were low in other elements such as As, Cd, Co, Cr, Pb, Sb and Zn. The specific surface area was measured for bottom ash, mechanical collector hopper ash and electrostatic precipitator ash, the values being 0.38, 0.27 and 3.06 m^2/g, respectively [18].

Elemental composition of flyash could vary depending on the coal sources [19]. A comparative account of the chemical composition of coal from different mines at India has been described in Table 1. They contained higher concentration of essential plant nutrients except nitrogen. Coals that are characteristically of high S content are low in pH. On the other hand lignite have lower S but higher Ca and Mg and produce ash characteristically high in pH [20]. Page et al. [21] reported that flyash with pH as low as 4.5 and as high as 12.0. Fe concentration of the Eastern U.S. coal derived flyash is higher than the western U.S. coal derived flyash.

X-ray analyses of flyash showed that 70% to 90% of the particles were glassy spheres, the remainder consisting of Quartz, Mullite, Hematite and Magnetite and a small portion of unburned Carbon. In addition, calcite (CaCO3) and Tourmaline have also been identified, and the presence of Borax, Rhodium, Boride, Boron arsenite and Boron phosphate has been also reported [22]. In India, the data available on flyash composition reveals that flyash particulates consisted of largely silica, alumina, iron oxides and carbon together with significant percentages of Ca, Mg, K, Na, Ti and variable amounts of trace elements [8].

Phung et al. [23] studied the release of trace elements from flyash in water and flyash treated soil; the amount of trace elements released from stockpiles of flyash depends largely on the pH, bonding between the element and flyash, its chemical form and physico-chemical properties of water. A decrease in pH causes some fraction of the trace elements (Cations) to be released into the dissolved phase despite their strong electrostatic attraction to the ash surface. In addition, the organic matter present in water could bring some of the trace elements in water by means of chelation reactions. The land surface disposal or construction utilization of heavy coal provides a source of leachate containing As, Cd, Fe, Mn and Se in considerable amounts and Al, Ba and Ti in lesser amounts. Evans and Giesy [24] while working on bioaccumulation study of some trace elements from flyash, found that bioaccumulation of Ti, Mn, Zn, Se, Cd and Hg was increased during the period of adequate setting in the basin.

In the flyash collected from electrostatic precipitators of thermal power stations consists of finely crystalline material, coarsely crystallized ceramic and many small spherical glass-like particles. The spherical, transparent appearance of flyashes indicated the melting of silicate minerals during coal combustion. The trace elements leachability in seawater has been reported by Crecelius [25] to find the leaching rate in marine environment. The insoluble elements like Fe, Se, La, Zn, Co and Ni are expected to be present as insoluble oxides in the glassy matrix of the flyash particles not easily leached. The solubility differences between flyash samples are due to particle size. The trace element activity in aquatic ecosystem and their impact on aquatic organisms varied depending upon the chemical species and the physical states that the element formed. Compellation of trace elements by both inorganic and organic legends played an important role in their transport in aquatic systems, influencing their solubility, sorption on sediments and uptake by biota. However, it has been suggested that complex formation of trace elements with organic substances controlled the concentration levels of trace elements in aquatic environment, hence lower the toxicity of a given concentration of total metal. Organic matters by means of chelation and compellation reactions solubilize Cd, Cu, Pb and Zn from flyash [26] (Table 1).

Table 1: Chemical composition of coal (air-dried basis) [28]

Coal fields	Moisture (%)	Ash (%)	Volatile Combustible (%)	Gross Claorific value (Kcal/kg)	Nitrogen (%)	Sulfur (%)	Phosphorus (%)	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)
Raniganj	0.6-11.2	8.8-47.0	11.5-39.2	11.5-39.2	11.5-39.2	0.2-1.1	Traces-0.505	47.8-70.0	21.4-28.6	21.4-28.6
Jharia	0.6-2.7	9.8-34.0	10.2-31.4	5205-7640	1.1-2.1	0.3-1.1	0.007-0.860	41.6-46.2	18.4-25.7	8.5-10.2
Talcher	2.9-9.6	6.8-48.4	22.7-38.6	3170-6750	0.9-1.7	0.3-0.9	0.002-0.164	55.3-68.2	18.4-25.7	3.2-13.6
Rajmahal	4.5-12.4	10.0-45.0	21.9-34.4	3440-5670	0.7-1.4	0.2-0.8	0.001-0.273	54.8-63.6	26.1-27.2	3.2-13.6

Depending on the coal sources, flyash varied widely in its pH and trace element contents, and the concentration of trace elements in flyash, in most cases, were considerably higher than their concentrations in coal but were comparable to those typically present in soil [12]. Elseewi et al. [27] obtained the positive relationship between electrical conductivity and the total salt concentration in flyash aqueous extracts. EC ranged from 0.177 to 14 m mhos/cm in most flyash samples; it was also found that the transition metals were selectively concentrated in the oxides of iron, alumina and manganese. In Indian flyash manganese is, however, probably not important, simply because of its low concentration (Fe-6.30%, Al-28% and Mn-473.05 ppm). Fulekar et al. [28] studied the heavy metals in Indian coals and corresponding flyash. They have found that concentration of heavy metals, such as Cr, Mn, Ni, Pb, Cd, Co and Zn increased with decreasing flyash particle size.

Coal flyash was separated into 54 - size density fractions (149 m, 1.6-3.2 g/cm^3) by supersonic sieving by Elseewi et al. [27]. On the basis of size and density distribution, elements were classified into three groups. Group - I elements are Si, Fe, Ca, Mg and Mn; group - II are Zn and Cu; whereas V, Cr and Ti are the elements of group - III. Maiti et al. [29] showed that the application of flyash to the agriculture lands has to be often supplemented with nitrogen to correct the nutritional deficiency, because the N content of flyash is usually very low. Singh et al. [30] reported that silica and alumina were the major constituents of flyash with other metal oxides present in trace. The concentrations of various oxides present in flyash were: SiO_2-56.04%, Al_2O_3-23.90%, CaO-2.22%, Fe_2O_3-1.26%, MgO-0.94%. They also reported the surface area and density of flyash were 5.77 m^2/g and 2.3 g/cc, respectively.

SPECIAL CHARACTERS OF FLYASH

- Low bulk density; water holding capacity; neutral to slightly alkaline pH; almost non-reactive particulates; low EC; presence of some essential elements for plant body; presence of many trace elements.
- Physico-chemical analysis:

Surface area (m^2/g)	pH	EC (m mhos/cm)	Organic carbon percent	Total nitrogen percent	Available nitrogen (ppm)	Available phosphorus (ppm)	Available potassium (ppm)	Exchangeable calcium (mc/100 g)	Exchangeable magnesium (mc/100 g)
5.77	7.3-8.0	0.10-0.20	0.10-0.30	0.009-0.042	10.7-67.2	2.1-4.2	26.5-88.5	0.69-1.02	0.08-0.42

Both the pH and EC slowly decrease with aging of the flyash dykes. The amount of organic carbon, total nitrogen, available nitrogen, available phosphorus, available potassium and exchangeable magnesium increase with aging of the flyash dykes, whereas that of exchangeable calcium doesn't give a steady figure [31].

- Flyash may be used in forestry and agricultural lands as a soil stabilizer; because of presence of several natural elements and being alkaline, application of flyash on lands has a marked effect on physico-chemical properties of soil from the point of view of crop production. The limiting factors in flyash utilization on land are changes in the soils, chemical equilibrium affecting its pH, salinity, levels of certain toxic elements etc. As a result of hydrolysis of calcium and magnesium oxides in ash, pH of soil increases. By application of flyash to soil at the rate of 80% by weight, pH of calcareous soil has been found to be increased from 8.0 to 10.8 and that of acidic soil increased from 5.4 to 10.0. In spite of these qualities, flyash application is not always recommended for reclamation of acid soils, because by reducing acidity it causes deficiency of nutrients like phosphorus, zinc and copper while increasing levels of the trace elements viz. molybdenum, selenium and boron, which in turn become toxic to plant bodies.
- Flyash has a good potential for being utilized in the agriculture fields in the following manner:

a. As a soil amendment to modify the pH of the soil.

b. As a soil conditioner to improve the physical and chemical properties of soil.

c. As a source of essential plant nutrients like P, K, Ca, Mg, Cu, Zn, Fe, Mn, etc.

- The physical, chemical and mineralogical properties of most of the common soil types and flyash are similar in many respects. Depending upon the soil type and its characteristics, flyash up to 560 ton/hectare can be used in agriculture/soil amendment.
- Due to comparatively medium silica content and fineness of the material, flyash undergoes rapid weathering. During combustion of coal, the material is produced containing all the mineral constituents of coal, but with a very low cation exchange capacity (3 meg/100 g). Many metal oxides are embedded in the glassy phase of the flyash and might be released over a period of time.
- Flyash contains higher concentration of essential plant nutrients like Ca, K Mo, Zn and B but a low content

of available N; therefore, an application of flyash to agriculture or forestry fields should be accompanied with supply of nitrogen.

- The ability of flyash particles of complex formation of trace elements with organic substances controls the concentration levels of trace elements in aquatic environment; hence lowers the toxicity of a given concentration of total metal.
- At the site of flyash application or disposal, the vertical distribution of pH and the contents of water-soluble constituents (Ca, Mg, K, Na and SO_4) produce alkaline leachate containing high amount of Ca^{2+} and SO_4^{2-}, which move downward with infiltrating water.

Impact of flyash on environment

Coal contains a variety of toxic heavy metals, and therefore, its impact on the environment has been a matter of concern in numerous laboratories [18,23,32-37]. The minerals contained in flyash may become available to plants after release into the environment. The large output of flyash particles by power plants and subsequent deposition of these on surfaces of vegetation and soils, increase the flux of several elements into the surrounding environment. The levels of these elements in the ecosystem can become significant even if these are in low concentration in coal. In fact, the decrease in flyash particle size increase the concentration of volatile trace elements, which when volatilized during combustion, tend to condense on the surface of particles at lower ambient temperatures [38,39]. Such elements enriched at the particle surface, are readily extractable in water and have a great potential for dissolution and release in the surrounding ecosystems [12,40-42]. It has been noticed that the particles smaller than 1 µm easily escape ESPs and the mass balance calculations indicate that elements like As, Bi, Cd, Cl, F, Hg, P, Pb, S, Se, Ti and Zn are retained less than many other elements by the electrostatic precipitators. Besides, larger particles are also emitted from mechanical collectors and due to low efficiency of electrostatic precipitators, several elements including Al, Ba, Ca, Co, Fe, K, Mg, Mn, Sr and Ti, which fail to get volatilized in the combustion zone, are sufficiently discharged under the conditions indicated above. Relatively few investigations have been carried out so far on the effects of flyash emission. Analysis of flyash samples deposited in soil and vegetation around power plants have provided information with respect to the elemental composition of flyash under these conditions [34,43-45]. The flyash samples usually contain essential plant nutrients, excepting N, at higher concentrations than that in ordinary cropland soils [12].

While evaluating the responses of plants to macro and microelements in flyash, workers have noticed that these may vary from beneficial effect at small concentrations [11] to harmful effects at high concentration. It has been noted that continuous deposition of even Ca^{2+} and Mg^{2+}-rich particles can disturb the nutrient balance of agricultural and forest soils [46]. It is, therefore, pertinent to understand the long-term effects of flyash on soil structure and plant growth and development. The flyash-contaminated sites, where there is regular accumulation of minerals in the soil, may differ from other mineral contaminated sites, which are not exposed to air pollutants in the following aspects [47]:

- A low level but constant contamination;
- Devoid of any major disruption in the soil nutrient conditions at least in the initial stages;
- No physical destruction of soil aggregates;
- No clear-cut boundaries of contaminated and uncontaminated sites.

The distribution of flyash constituents and their exchange with biological systems would depend upon physico-chemical nature such as volatility of the elements and also upon local atmospheric circulation and precipitation. It is acknowledged that the volatile elements being most readily available for plant uptake are enriched to the vegetation growing around a power plant as these elements are likely to be present either in gaseous form on in the observed condition at the surfaces of particulate emission products [40,48,49]. The elements Zn and S, being most volatile, are easily enriched in leaf tissues while Ca, Mg and K being less volatile, are available in various degree to plants, depending on their interactions among themselves and with gaseous pollutants present in the air. The foliar concentrations of Fe, Mn and Zn were found to be positively correlated with distance in Eucalyptus moluccana, but no elements in *Eucalyptus orebra* leaves could be correlated with distance, and Zn concentrations in the former species varied from 10.5 to 42.5 µg/g [48]. The elevated concentrations of elements in the above study could be found up to a distance of 28 km for which the tall stacks and the buoyant plume characteristics of the emissions were largely responsible. The importance of stack height in determining elemental input to ecosystem has been worked out by Evans et al. [42] who indicated that 34% of emitted flyash fall within 10 km of a power plant with a 38 m tall stack, but a power plant with a 300 m tall stack, deposited only 6% of emitted ash within 5 km. The low stack height (<100 m) facilitates increased accumulation of elements at sites close to power plant, which then decrease in concentration with distance. However, only particles with respectively large fall velocities could be expected to demonstrate a monotonic decrease in deposition rate with distance from the emissions source and consequently a lack of correlation between K and between some elements and distance may be associated with these dispersion characteristics [49]. The mode of entry and uptake of elements enriched in flyash, especially those under study, has not been properly elucidated so far. Transport of elements across intact leaf cuticles is a slow process especially in comparison with stomata uptake. Under field conditions leaf cuticles are subject to physical abrasions, chemical interactions and biological attack from pathogens [50].

Ash, when blown by wind, not only creates air pollution but also affects adjacent croplands by deposition of fine silica and other particles. Sometimes, due to heavy rains, dissolved salts and non-dissolved suspensions of ash, are carried into streams and rivers. Water percolation through ash ponds also contaminates ground water. The sequential change in vegetation composition in response to environmental changes has been marked in different ash-dykes of thermal power plants. Age of the dyke is certainly one variable that contributes towards the change of several stages from almost a hydrosere and tending towards a climax community. The ash-dykes are considered as stress sites as coal ashes are considered a potentially hazardous substance because of their elevated trace element concentrations [51]. Where ash content is high, stack height is low and control equipment is less efficient, the particulate pollutants may tend to accumulate in the soils and vegetation of power plant area.

IMPACT OF FLYASH ON VEGETATION

It has been recognized that the content of three major elements nitrogen, phosphorus and potassium in flyash is usually low; on flyash application, the nutrient status in soils alters depending on the kind and rate of flyash, kind and nutrient content of soil and plant species assuming that all other plant growth conditions are optimal [27]. The positive effects of flyash on plant are described mainly to a shifted chemical equilibrium of soils. Also, flyash alters the physical conditions, adding several elements to the soil. Application of flyash to either calcareous or acidic soils at rates up to 8% (by weight) produced higher yields of several agronomic crops, which were attributed to increased availability to plants of S from ash. High input of flyash to soil may also lead to increased Mo in forage crops without being associated with improved yields, but attaining the concentrations potentially toxic to animals feeding on the forage [12,16]. Due to flyash amendment, plants even at higher pH significantly took up an ionic constituent of soil like S, MO and Se. The higher content of Se was found to be proportional to either rates of flyash application or Se content of flyash [52,53]. Although Mo and Se are not phytotoxic, yet their uncontrolled accumulation (from 5 to 20 ppm for Mo and 4 to 5 ppm for Se) would be potential hazard to livestock animals [12,54].

Consequent to the negative effects on plants, the major constraints involved in flyash application to land are unfavorable changes in the soil equilibrium including increases in pH, salinity and levels of certain toxic elements. Increase is soil pH due to hydrolysis of CaO and MgO present in flyash may enhance the pH of a calcareous soil from 8.0 to about 10.8 and that of an acidic soil from 5.4 to about 9.9. Soil salinity could increase substantially when soils are amended with fresh flyash [22,55-58]. But weathering of flyash with consequent stabilization under various storage conditions may considerably reduce the salinity impact due to leaching of soluble salts [59]. Boron in flyash has been proved to be major phytotoxic constituent, which is readily available to plant and this element has been associated with significant reductions of crop yields [56,60,61].

Direct effects

In the environs of thermal power plants, where flyash is one of the main air pollutants, density of stomata, the stomata index and size of stomata pore and epidermal cells decrease while the frequencies of epidermal cells and trichomes increase [62]. Leaf and fruit necrosis are found on Citrus and other species due to vanadium - rich acidic ash [41]. The effects of thermal power plants emission including flyash on tobacco and corn plants were investigated by Merakchiska-Nikolova et al. [63]; dry matter production, photosynthesis, respiration and the amount of pigments were reduced. Rate of photosynthesis, however, increased in corn plants, apparently due to the higher adaptive potential of the plant. Similarly, productivity of Oak stand was found to be reduced due to the power plants emission including flyash [64]. A review by Smith [65] of coal combustion and health of forest ecosystem raised some important issues of the effects of air contaminants on forested areas.

Indirect effects

Literature on the effect of flyash on soil-plant relationship is numerous, focusing mainly on the utilization aspect of this power plant waste; field and green house studies both indicate that many chemical constituents of flyash may benefit plant growth and can improve agronomic properties of soil. Because all natural elements are present in coal ash in trace amount, the addition of flyash to soil changes physical properties, mineral composition and chemical equilibrium of the soil. The interaction between plants and flyash-amended soils are also complicated by varying edaphic factors and plant species [51]. In field studies the natural variation may obscure the effects of elemental deposition, so pot trial method with one or two indicator plant species is advisable. Increase in dry matter yields were obtained in flyash amended soils, but these were associated primarily with correction of either macro or micronutrient deficiencies. Higher yield was attributed to increased availability of S. On acidic strip mine soils, the application of flyash increased yields of several crops due to increased plant nutrient availability, i.e., Ca^{2+}, Mg^{2+}, which also prevented the toxic effects of Al^{3+} and Mn^{2+} and other metallic ions by neutralizing the soil acidity [66-68]. The major plant nutrients (P, K, Ca and Mg) were affected inconsistently by ash application. Deficient P levels in tissues were observed. It was shown that P in flyash was considerably less available to plants than the P from mono-calcium phosphate [69]. Of the basic Cations, Ca^{2+} and Mg^{2+} appeared to be taken up preferentially by legumes. Martens et al. [15] demonstrated that K from KCl was slightly more available to plants than from flyash. Inconsistencies in the uptake of K, Ca and Mg are probably caused by the interaction among these elements in the root - soil solution interface or within the plant system. For example, Ca and/or Mg can reduce K uptake by plants grown in flyash treated soils. The micronutrients Mn, Zn, Cu and Fe from flyash are not consistently available to plants. This may be due to the increase in soil pH, inducing deficiencies in these nutrients. Contents of S were found to increase in several crops [56,58,61].

Weathering of flyash helps in vegetation development

The distribution of microorganisms viz. bacteria, actinomycetes and fungi, in the flyash dykes of different ages in relation to vegetation development were studied by Banerjee and Kashyap [70]; the study was done with a view to assess the time dependent changes in species composition, nutrient status and biological activities. With the increase in the age of ash dykes (0.5 to 5.0 years), the number of plant species (shrubs and herbs) increased. The population of all the organisms increased with the increase of the age of dykes. Nutrient status of the ash dykes also increased with time. The growth of all the organisms was significantly influenced by organic carbon, available nitrogen, phosphorus, potassium, exchangeable calcium and magnesium. The results showed that with the progress of weathering, the characteristics of flyash improved nutritionally allowing the plant species to invade with an increase in the microbial activities.

Morphological and biochemical changes in the leaves in plants grown on flyash

In India, *Ipomea cornea, Cassia tora* and *Acacia nilotica* grow naturally in almost all flyash dykes. But leaf injury in the form of chlorosis and necrosis is common. Sizes of leaves get reduced with a sharp decrease in leaf weight and the photosynthetic area. There is a sharp decline in the levels of carbohydrate, protein, chlorophyll and ascorbic acid in comparison to that on normal soil, when, the phenol content gets higher [71]. Since major part of the ash comprises SiO_2, Al_2O_3 and oxides of Fe, the leaves directly through the stomata absorb these oxides when the ashes are deposited on the leaves and also through the uptake of the oxides by the root system. The increase of phenols helps in imparting resistance to the plants against stress conditions and insect attacks.

Impact of flyash on foliar chemical and biochemical composition of naturally occurring ground flora

Banerjee et al. [72] when worked in a tree plantation on a 12 years old flyash dyke at Shaktinagar (UP) thermal power plant found that the flyash severely affected the chemical and biochemical composition of the leaves. The amount of N, P, K, Ca and Mg decreased amongst the chemicals, and that of protein, carbohydrates, chlorophyll and ascorbic acid decreased amongst the bio-chemicals with a significant rise in the amount of phenols. Since the major part of the ash comprises SiO_2, Al_2O_3 and the oxides of iron and other toxic metals, the leaves through stomata absorb these oxides when the ashes are deposited on the leaves and also through the uptake of the oxides by the root systems. The increase in phenols helps in imparting resistance to the plants against stress conditions and insect attacks. The results also revealed that although the flyash is refractory in nature, it can well respond to some species if planted after its stabilization which normally takes 4 to 5 years. Species like *Gmelina arborea*, *Grevillea pteridifolia* and *Emblica officinalis* were more suitable for planting in that site with respect to amelioration and biomass production. Some other species like *Albizia procera*, *A. lebbek*, *Azadirachta indica*, *Acacia catechu*, *Prosopis juliflora* etc. might also grow well. Planting of these species resulted induced succession development in which Tephrosia – Desmodium – Polygonum were found to be the stable community and these 3 species shared the major niche space.

Flyash may be used as seed germination medium

In another group of experiment Banerjee et al. [73] studied the germination biology of *Acacia auriculiformis* and *Azadirachta indica* seeds in a series of media containing flyash. They found that the best medium for *Acacia auriculiformis* seeds was flyash+soil (1:1) and for *Azadirachta indica* it was flyash+soil+sand (1:1:1); these

Table 2: Physico-chemical characteristics and nutrient status of flyash of different aged dykes and forest soil

Parameters	Flyash dyke (age in months)					
	A	B	C	D	E	F
	6	12	24	36	60	Natural Forest
Particle size (%) >2.0 mm	48.0	51.2	53.5	57.2	59.2	56.8
2.0-0.2 mm	11.2	8.2	10.5	11.3	15.3	13.2
<0.2 mm	39.5	36.3	27.5	26.3	25.5	30.0
pH (1:2.5)	8.0	7.7	7.6	7.4	7.3	6.2
EC (m mohs/cm)	0.20	0.19	0.14	0.13	0.10	0.07
Organic C (%)	0.100	0.110	0.180	0.268	0.301	0.560
Total N (%)	0.009	0.016	0.028	0.034	0.042	0.050
Available N (ppm)	10.7	11.2	29.3	46.2	67.2	183.0
Available P (ppm)	2.1	3.0	3.9	3.6	4.2	6.4
Available K (ppm)	26.5	42.6	67.1	67.6	88.5	193.5
Exch. Ca^{2+} (me/100 g)	0.89	1.02	0.81	0.69	0.73	2.95
Exch. Mg^{2+} (me/100 g)	0.08	0.10	0.31	0.41	0.42	1.20

combinations were also beneficial for increase in shoot height, root weight, leaf weight and total biomass. The specific recommendations can be made for large-scale plantation in flyash overburden. They also commented that before raising plantation in flyash overburden, the pits should be filled up with flyash:soil:sand in a proportion of 1:1:1.

Development of vegetation on ash-dykes

The sequential change in vegetation composition in response to environmental changes has been marked in different ash dykes of the thermal power plants. Age of the dyke is certainly one variable that contributes towards the change of vegetation composition and the other is the change in the serial stages from almost a hydrosere and tending towards a climax community. The ash dykes are considered as stress sites as coal ashes are considered potentially hazardous substances because of their elevated trace element concentrations [12]. It is necessary to study genesis and aging very closely in these stress sites so that artificially such process can be tried with. With this view, Mishra et al. [74] conducted a study on the vegetation dynamics and spoil characteristics of an age series of flyash dykes of Chachai, M.P. The physico-chemical characteristics and nutritional status of ashes of different sites A (0.5 year), B (2 year), C (2 years), D (3 years), E (5 years) and F (natural forest) is given in Table 2 [51]. The ashes were generally alkaline in reaction; pH is highest (8.0) in 6 months old dyke and it gradually decreased with the passage of time.

When the Important Value Index (IVI) of the species available in the sites A, B, C, D, E and F were analyzed, it appeared that the number of species increased steadily as a factor of age of the dyke; only 3 species were found in the dyke of age 6 months old, when 33 species were found in the dyke aged 60 months. Interestingly, the natural forest adjacent to these ash dykes accommodated only 32 species and this was a completely scrub jungle.

The dominance index (cd value) decreased gradually as diversity index increased. The natural forest had more dominance index than 36 months and 60 months old sites. Odum [75] stated that species diversity tends to increase during ecological succession, but this trend doesn't necessarily continue in the older or mature stages. In the natural forest around, severe grazing on the other hand acted as stress and reduced the species to an unpalatable few. The species richness index (d) increased as the age of the dyke increased. Evenness of species distribution increased up to 24 months and decreased after that. Mc Naughton [76] stated that increased diversity and decreased dominance are associated with increased stability.

In the succession series the species composition is worth mentioning. In the 6 months old dyke, there was plenty of water logging as flyash was flown along with water to the dykes. The dykes with mixture of flyash and water dry up only after the pond was abandoned. The water logging condition persisted for about a year or more.

In the six months old dyke, invasion of species like *Typha angustata*, *Ipomea cornea,* etc. were seen which are generally suited for aquatic habitat. The community was represented by Typha and Ipomea and was generally classified within Red-swamp stage or amphibious stage in a hydrosere. Due to successive decrease in water level along with amphibious species, some species from Gramineae such as *Pennisetum hohenackeri*, *Eragrostis ciliaris* and *Cynodon dactylon* gradually tried to dominate the area as seen in 12 months old ash dyke. These species formed a mat like vegetation with the help of rhizomatous system and resulting high rate of transpiration. Due to rapid loss of water and also changes in spoil physico-chemical composition caused by vegetation cover marshy vegetation was replaced gradually by mesic vegetation. The plant community in the 12 months old dyke thus can be put under Typha – Pennisetum – Eragrostis community where the graminaceous species like Pennisetum and Eragrostis gained ground.

In the 24 months old dyke which almost became unsuitable for the growth of marshy and amphibious species (though Typha exists with very low IVI value), the community here can be classified under Pennisetum – Xanthium – Eragrostis where Typha were pushed behind as spoil become drier for a considerable time in a year. In between Pennisetum and Eragrostis, Xanthium introduced itself. The species was an exotic and gregarious one and well established itself in an area where rapid vegetative succession was in progress. In 36 months old dyke the community identified was of Xanthium – Pennisetum – Phyllanthus community based on their IVI values. Here Xanthium became the dominant species pushing aside Pennisetum to second position and Phyllanthus simplex emerged to the third position. In this dyke, tree species like Schima and Madhuca established themselves and many woody shrub species as *Tephrosia purpurea*, *Casia tora*, *Hyptis suaveolens*, *Pithecellobium dulce* successfully invaded the ecosystem. By the time of disappearance of marshy vegetation and accumulation of humus, some tree species began to appear. In the 36 months old community some tree species were found with very low IVI value. In the 60 months old ash dyke tree species like *Schima sulcatum*, *Madhuca longifolia* and *Ficus glomerata* appeared and established themselves. Crotalaria – Xanthium – Tephrosia community dominated the dyke. *Cassia tora*, which was another woody shrub species, appeared as a dominant one. *Pennisetum hohenackeri* was pushed to much lower position. *Tephrosia purpurea*, a woody shrub and *Crotalaria pollida*, a leguminous species appeared as two of the dominant species.

The study of natural vegetation cover of the region showed that there existed at least 13 species in the community among which *Lagerstroemia parviflora*, *Ficus religiosa*, *Butea monosperma* and *Haldina cordifolia* were dominant so far their IVI values were concerned. The community was Cassia – Tephrosia – Lagerstroemia dominated. So, it was predicted that the woodland stage of 60 months old dump would be invaded by more and more tree species to reach the climax stage, i.e., the forest stage [51] (Table 2).

BIOLOGICAL RECLAMATION OF FLYASH BY FOREST PLANTATION

When ~3% of the total flyash produced is being currently utilized for various industrial purposes, there is a great potential of ash utilization for growing the tree crops. Singh et al. [77] and Mishra et al. [78] tried to raise plantation of few forestry species on flyash-disposed area to study their suitability.

The study area (Chachai) of Singh et al. [77] was near the Amarkantak thermal power station of MPEB where flyash was deposited in the flyash dyke. During 1988, pits of 45 cm^3 with 2 m × 2 m spacing were dug in flyash dyke. Two months old seedlings of 12 species were transplanted in the pits in randomized block design had following treatments: soil (T_1), flyash (T_2), soil+sand+flyash 1:1:1 (T_3) and soil+sand+flyash+compost 1:1:1:1 (T_4). It was found that Eucalyptus hybrid and *Acacia auriculiformis* grew well than the rest of the species. After 7 years, the maximum diameter (13.4 cm) was found in *Acacia auriculiformis* and the maximum height in Eucalyptus hybrid (8.64 m) in the T_4 treatment. The authors also observed good plantation of *Dalbergia sissoo* and *Pongamia pinnata* at Korba thermal power plant at least up to 3 years (personal experience, data not shown). As the biological environment of flyash is sterile, the microbial activities are minimum, which are normally present in the soil. But after seven years of plantation in the T_2 treatment, the microorganisms were found active as evidenced from the presence of various ground floras like *Cassia tora*, *Tridex procumbens, Indigofera pulchella*, *Lantana camara*, *Ipomea cornea*, *Atylosia scarabaeoides*, *Crotolaria* spp., *Desmodium triflorum*, *Elephantopus scaber*, *Typha angustata*, *Ergrostis tenella,* etc.

Mishra et al. [78] conducted pot culture experiment to study the performance of different nitrogen fixing (NFT) and non-nitrogen fixing (non-NFT) tree species on flyash to reclaim it biologically. After computing 1 year data in respect of height, diameter and biomass production and the specific recommendation were made for large scale plantation in flyash. Amongst NFTs, *Sesbania grandiflora*, *S. sesban*, *Albizia procera* and *Acacia nilotica*, were the better-suited species while amongst non-NFTs, *Gmelina arborea*, *Eucalyptus* hybrid and *E. torreliana* were found suitable. Before raising the above-said species in flyash disposal area, the pit should be filled up with 1:1:1 proportion of flyash, soil and compost for successful plantation. Because of high porosity, the moisture retaining capacity of flyash is low; use of mulches was found to delay the process of drying by reducing the evaporative loss [79]. Mulches by virtue of reduction in moisture loss help in increasing growth biomass production, nodulation and the leaf area. Leaf-litter was beneficial for increasing height growth, root length, collar diameter and leaf area, while gravel mulch was found to be more suitable for increasing aboveground biomass [74].

NON-BIOLOGICAL UTILIZATION OF FLYASH

The excellent Pozzolanic properties enables flyash to be extensively used in the manufacture of cement as a filler material, concrete, ceramics, construction fills, road base and mineral filler in asphalt mix. The term “Pozzolanic” is derived in oilfield glossary, which means to pertain to material that possesses little or no cement-like value, but that is capable of reacting chemically with calcium hydroxide at ordinary temperatures to form compounds with cement-like properties. Apart from uses in agriculture and forestry and manufacture of fertilizers, other major non-biological uses of flyash are: Flyash bricks/blocks, Cellular concrete products, Light weight aggregates, Concrete and mortar, Cementing manufacturing, Asbestos products manufacturing, Embankment/Back fills/Land Development, Controlled low strength fill material (CLSM), Mine filling, Manufacture of distemper, Floor and wall tiles, Refractory bricks, Manufacture of ceramics, Use of ferro cement, Recovery of metals, Use in grouting, Manufacture of alum, Domestic cleaning powder, Use in manufacture of synthetic wood, Extraction of Cenospheres (Cenospheres are mainly made up of SiO_2 and Al_2O_3, almost similar in composition to that of ceramics. Flyash is used during the separation process of Cenospheres).

Clay-flyash bricks

Major considerations for flyash utilization in the production of burnt clay-flyash burning products are:

a. Compatible physico-chemical and mineralogical properties.
b. Close resemblance of microcrystalline phases of heat-indurate clay mass with flyash constituents.
c. Saving in thermal energy.
d. Capacity to modify the drying behavior of sensitive plastic clays.
e. Need for conservation of natural resources.

Manufacturing process of clay flyash bricks by manual or extrusion process involves mixing of flyash (60%) with clays of moderate plasticity. The green bricks are dried under ambient atmospheric conditions or in shade to equilibrium moisture level of below 3%. Dried bricks are fired in traditional brick kilns at 1000° ± 30°C with a soaking period of 5-7 h at maturing temperature. This technology has great potential to reduce not only precious top soil and consumption of coal in making conventional clay bricks, but also requires minimum changes in existing set up at kiln sites and is not very much susceptible to the quality of ash.

Flyash-sand-lime bricks

In presence of moisture, flyash reacts with lime at ordinary temperature and forms and compound possessing cement-like properties. After reactions between lime and flyash, calcium silicate hydrates are produced which responsible for the high strength of the compound. Bricks made by mixing lime and flyash are, therefore, chemically bonded bricks. These bricks are suitable for use in masonry just like common burnt clay bricks. These bricks have the following advantages over the clay bricks:

a. Possess adequate crushing strength as a load-bearing member.
b. Have cement color in appearance, are uniform in shape and smooth in finish and require no plastering for building work.
c. Are lighter in weight than ordinary clay bricks.

Flux bonded flyash bricks, blocks and tiles

The Regional Research Laboratory (CSIR), Thiruvananthapuram and TNO TPD (TNO: Toegepast Natuurwetenschappelijk Onderzoek, Netherlands Organization for Applied Scientific Research; TNO Institute of Applied Physics is known as TPD) in the Netherlands have together developed a process for the manufacture of bricks, tiles and blocks with flyash content. The material is called “CFBA-Building Products” (patented).

The process is similar to the one in the conventional tile industry: flyash is mixed with less than 10% plastic clay and a few additives and tiles, bricks or blocks are pressed. The shapes are fired in the range of 900°C to 1000°C to make the final product. More than 85% of flyash is used in the process. The process is based on the formation of low melting fluxes at the firing temperature reactive glass binder phase. The bricks, tiles and blocks are brick red in color, but changing the initial composition can make a variety of colors. The process has been tested at pilot plant scale under factory conditions.

Cold bonded lightweight flyash bricks, blocks and tiles

TNO TPD of the Netherlands and the Regional Research Laboratory (CSIR), Thiruvananthapuram, has developed a new lightweight building material called “Keraton” (ceramic concrete), which can be utilized in the production of building blocks, bricks and tiles. In the making procedure, flyash and other waste materials are mixed and a cold bonding agent is added. The mixture is cast in moulds and then the moulds are processed for 4 min in a microwave oven. After cooling and de-molding the building blocks are ready for transportation to the building site. The products can be applied as a lightweight material in the house building industry and utility building, such as stables, barns, garages, etc. and they have very good insulation properties.

Manufacture of cellular concrete products

There are two types of processes in vogue for manufacturing cellular concrete products:

a. Process I: This process necessarily employs autoclaving of the product.

b. Process II: This process avoids autoclaving and the product can be cast at sites and normal curing methods are employed.

Process I: Autoclaved Aerated Concrete (AAC) blocks and other building elements are manufactured by the process of mixing flyash, quicklime, cement and gypsum along with water in a high speed mixer to form slurry. A small amount of foaming agent (Aluminium powder) is added and mixed into this slurry, which is then poured into large steel moulds to fill the mould partially. Because of reaction between aluminium powder and hydrated lime, the mix begins to rise until the mould is completely filled with a porous mass, which is still soft. After 3 h, as a result of hydration of un-slaked lime and the cement, the mixture sets sufficiently to be cut into required sizes of blocks and panels.

To prepare the material for cutting into required sizes, the mould is turned through 90 degreed before cutting. Three sides of the mould are then stripped off and the set mass (AAC cake) inside is positioned on its narrow long side, which acts as a support as well as curing plate for the mass (cake).

Process II: In this process Cellular Lightweight Concrete (CLC) is produced by mixing sand, flyash, cement, water and stable foam in requisite proportion in ready mix plant or ordinary concrete mixer. The mixed slurry is then poured into moulds of pre-cast blocks/structural components/assembled formwork of building elements or over-flat roofs for thermal insulation. The foam is produced by a foam generator by using a foaming agent; the foam contains isolated air bubbles, which create millions of unconnected tiny voids/cells in the mix resulting in lighter weight of concrete. CLC can be produced in a wide range of controlled densities from 400 kg/m^3 to 1800 kg/m^3 as against conventional concrete of density of 2400 kg/m^3. The use of CLC in housing construction can result up to 40% reduction of the dead load.

Sintered lightweight aggregate

Sintered lightweight aggregate is produced by pellet formation or nodulation of flyash and sintering of the pellets or nodules at a temperature of 1000-1300°C. Un-burnt fuel in the flyash nodules supports ignition. Sintered lightweight aggregates substitute stone chips in concrete reducing dead weight. It can also be used for various purposes such as in manufacture of structural lightweight concrete and pre-cast lightweight concrete building units for the use of as load and non-load bearing elements, etc. This procedure has good potential in places where flyash is locally available and stone aggregates are costly. This technology has been developed by the RRL, Bhubaneswar.

Man-made aggregate (MMA)

MMA is produced is the lightweight aggregate from any type of raw material such as flyash, kiln dust, rock dust, silt etc. Cement based slurry is mixed with preformed stable foam to give foamed concrete in the density range of 300-1200 kg/m^3. This foamed concrete is poured into 500 mm wide and deep open channels and is allowed to set. MMA requires no primary energy and the hydration of cement is achieved with water curing.

UTILIZATION OF FLYASH IN THE MANUFACTURE OF CEMENT CONCRETE AND MORTAR

Flyash is extensively used in manufacturing of cement concrete in most of the developed countries such as USA, UK etc. Addition of flyash in cement concrete mix improves the properties of concrete as well as reduces its cost. During the setting and hydration of concrete, lime is liberated. When flyash is available in concrete mix, it reacts with this lime and forms additional cement alike material. Some of the benefits of flyash incorporation in cement concrete are:

- Greater long-term strength
- Improved workability
- Reduced heat of hydration
- Reduced permeability
- Resists Sulfate attack
- Reduced alkali-aggregate reactions

- Reduction in cost of concrete
- Increased resistance to corrosion

Using Roller Compacted Concrete (RCC) Technology for mass concreting, 60-70% cement was replaced with flyash; for the first time in India, RCC was used for construction of 3 dams under a technology demonstration project of the Flyash Mission at Ghatnagar Pumped Storage Scheme, Maharashtra [80,81].

Manufacture of cement

The manufacture of Portland Pozzolana Cement (PPC) conforming to IS 1489-Part I is a commercially viable area wherein flyash can be utilized in considerable quantity. Flyash can be utilized in its manufacture through either of the following methods:

- As a raw material, i.e., burning of flyash with limestone and coal in kiln.
- Grinding of cement clinker and flyash together in the Mill.
- By intimate and uniform blending of ordinary Portland Cement with fine flyash.

In India, the cement companies prefer to adopt the second method. PPC made up of using flyash produces lesser heat of hydration and offers greater resistance to attack of aggressive water and sulfates as compared to ordinary Portland cement. It also reacts with free lime liberated during hydration of the cement and forms calcium-silicate hydrated bond, which gives more strength to the concrete or mortar.

Asbestos cement products

Asbestos cement industries utilize flyash as a Pozzolanic material as a replacement of cement. This industry, however, requires very fine ash particles having high lime reactivity, i.e., ash collected from normally 3rd filed of Electrostatic Precipitators.

Use of flyash in road construction

Exhaustive research has proved that flyash can be successfully and economically in the pavement layers of road construction. There are many techniques available for this purpose:

1. Use as granular sub-base material.

2. Use as soil stabilizer.

3. Use of lime/cement flyash stabilized soil.

4. Stabilized flyash in the sub-base and base course.

5. Utilization of flyash in semi-rigid and rigid pavement as:

- Lean cement flyash concrete.
- Lime flyash concrete.
- Flyash in rigid pavement construction.
- Flyash as filler in bituminous/asphalt concrete.
- Roller compacted concrete.

Embankment/back fills/land development

Flyash is a relatively lightweight material as compared to earth. The well-compacted flyash exhibit good shear strength comparable to soils normally used in earth-fill operations. Its light unit property is particularly advantageous in situations where filling is necessary on relatively weak subsoil. Coal ash in its loose state has good permeability. This characteristic is conducive to achieve better rate of construction during rainy season. In addition to this, it is easier to compact coal ash as compared to earth as its moisture-density curve is more is even. All these properties of coal ash make it a desirable material for use in embankment construction, backfilling and land development works.

Utilization of flyash for reinforced embankment constructions: Embankments can be constructed using reinforced earth technique adopting flyash as the fill material. Provision of reinforcements for ash embankment reduces the shear stress and minimizes lateral deformations. Ash embankments constructed using geo-textile reinforcement can have steeper side slopes; such structures can be used as noise barriers along highway.

Controlled low strength material (CLSM)

Fly ash can be utilized in the manufacture of CLSM. This is a fluid mixture made up of small quantity (4-6%) of Portland cement, sufficient quantity of water and large quantity of flyash or fine aggregates or both. The CLSM is neither a concrete nor a soil cement but is has property similar to both. CLSM or flyash slurry fill material provides many advantages as follows:

- Excellent flow-ability; can be filled with minimal efforts; fills all the voids, spaces.
- No compaction or curing required.
- Easy to produce and apply.
- No settlement after final set.
- Low unit weight.
- Can be dug back later, when required.
- Different strengths can be designed as per retirement.
- Reduced labor cost.
- Cost effective.
- Uses large quantum of ash.

The CLSM or flyash slurry fill material gets its strength from cement or Pozzolanic reaction of flyash. Dry flyash or pond can be used in this. CLSM can replace compacted soil as structural fill; this is ideal for use in restricted access areas where placing and compaction is difficult such as back filling in narrow trenches, filling of trenches of utilities, sanitary and storm sewers, pipes, abandoned underground structures such as mines, tunnels, tanks, wells, etc.

USE OF FLYASH IN MINE FILLING

Opencast mines: Use of ash in backfilling of opencast mines and stowing of underground mines is a major area of flyash utilization. After the completion of mining, backfilling may be done with the overburden materials along-with flyash. But in fact in India, this operation will take some more time, as most of the mines are younger in age yet to be refilled.

Underground mines: Usually, backfilling of underground mines is done with river sand. In a collaborative project with Central Mining Research Institute (CMRI), Dhanbad, NTPC Ramagundam, has tried the use of 1,00,000 tons of bottom ash for the stowing operations at Singreni; the trial has been found to be feasible.

Development of vegetation on ash-dykes

The sequential change in vegetation composition in response to environmental changes has been marked in different ash dykes of the thermal power plants. Age of the dyke is certainly one variable that contributes towards the change of vegetation composition and the other is the change in the serial stages from almost a hydrosere and tending towards a climax community. The ash dykes are considered as stress sites as coal ashes are considered potentially hazardous substances because of their elevated trace element concentrations. It is necessary to study genesis and aging very closely in these stress sites so that artificially such process can be tried with. With this view, Mishra et al. conducted a study on the vegetation dynamics and spoil characteristics of an age series of flyash dykes of Chachai, M.P. The physico-chemical characteristics and nutritional status of ashes of different sites A (0.5 year), B (2 year), C (2 years), D (3 years), E (5 years) and F (natural forest) is given in Table 2. The ashes were generally alkaline in reaction; pH is highest (8.0) in 6 months old dyke and it gradually decreased with the passage of time.

When the Important Value Index (IVI) of the species available in the sites A, B, C, D, E and F were analyzed, it appeared that the number of species increased steadily as a factor of age of the dyke; only 3 species were found in the dyke of age 6 months old, when 33 species were found in the dyke aged 60 months. Interestingly, the natural forest adjacent to these ash dykes accommodated only 32 species and this was a completely scrub jungle.

The dominance index (cd value) decreased gradually as diversity index increased. The natural forest had more dominance index than 36 months and 60 months old sites. Odum [75] stated that species diversity tends to increase during ecological succession, but this trend doesn't necessarily continue in the older or mature stages. In the natural forest around, severe grazing on the other hand acted as stress and reduced the species to an unpalatable few. The species richness index (d) increased as the age of the dyke increased. Evenness of species distribution increased up to 24 months and decreased after that. Mc Naughton [76] stated that increased diversity and decreased dominance are associated with increased stability.

In the succession series the species composition is worth mentioning. In the 6 months old dyke, there was plenty of water logging as flyash was flown along with water to the dykes. The dykes with mixture of flyash and water dry up only after the pond was abandoned. The water logging condition persisted for about a year or more.

In the six months old dyke, invasion of species like *Typha angustata*, *Ipomea cornea,* etc. were seen which are generally suited for aquatic habitat. The community was represented by *Typha* and *Ipomea* and was generally classified within Red-swamp stage or amphibious stage in a hydrosere. Due to successive decrease in water level along with amphibious species, some species from Gramineae such as *Pennisetum hohenackeri*, *Eragrostis ciliaris* and *Cynodon dactylon* gradually tried to dominate the area as seen in 12 months old ash dyke. These species formed a mat like vegetation with the help of rhizomatous system and resulting high rate of transpiration. Due to rapid loss of water and also changes in spoil physico-chemical composition caused by vegetation cover marshy vegetation was replaced gradually by mesic vegetation. The plant community in the 12 months old dyke thus can be put under Typha – Pennisetum – Eragrostis community where the graminaceous species like Pennisetum and Eragrostis gained ground.

In the 24 months old dyke which almost became unsuitable for the growth of marshy and amphibious species (though *Typha* exists with very low IVI value), the community here can be classified under Pennisetum – Xanthium – Eragrostis where Typha were pushed behind as spoil become drier for a considerable time in a year. In between Pennisetum and Eragrostis, Xanthium introduced itself. The species was an exotic and gregarious one and well established itself in an area where rapid vegetative succession was in progress. In 36 months old dyke the community identified was of Xanthium – Pennisetum – Phyllanthus community based on their IVI values. Here Xanthium became the dominant species pushing aside Pennisetum to second position and Phyllanthus simplex emerged to the third position. In this dyke, tree species like Schima and Madhuca established themselves and many woody shrub species as *Tephrosia purpurea*, *Casia tora*, *Hyptis suaveolens*, *Pithecellobium dulce* successfully invaded the ecosystem. By the time of disappearance of marshy vegetation and accumulation of humus, some tree species began to appear. In the 36 months old community some tree species were found with very low IVI value. In the 60 months old ash dyke tree species like *Schima sulcatum*, *Madhuca longifolia* and *Ficus glomerata* appeared and established themselves. Crotalaria – Xanthium – Tephrosia community dominated the dyke. *Cassia tora*, which was another woody shrub species, appeared as a dominant one. *Pennisetum hohenackeri* was pushed to much lower position. *Tephrosia purpurea*, a woody shrub and *Crotalaria pollida*, a leguminous species appeared as two of the dominant species.

The study of natural vegetation cover of the region showed that there existed at least 13 species in the community among which *Lagerstroemia parviflora*, *Ficus religiosa*, *Butea monosperma* and *Haldina cordifolia* were dominant so far their IVI values were concerned. The community was Cassia – Tephrosia – Lagerstroemia dominated. So, it was predicted that the woodland stage of 60 months old dump would be invaded by more and more tree species to reach the climax stage, i.e., the forest stage.

DISCUSSION AND CONCLUSION

Flyash is the major solid waste product and also a particulate pollutant derived from the combustion of pulverized coal in thermal power plants. The pollutants when released into the environment, affects vegetation directly or indirectly. With recent introduction of the super thermal power plants, production and disposal of flyash will continue to be one of the major national problems. However, the research and development units are active and are trying to innovate methods to reduce flyash pollution with sophisticated techniques like ammonia prevention technology (not described yet in their reports). A lot of emphasis is being laid on the biological and non-biological utilization of flyash. As the physico-chemical properties of flyash depends on the type and nature of coal burnt, its special effect with respect to the particular affected areas, especially on the vegetation, is a matter of concern for the environment research explorers.

REFERENCES

[1] Rout RC. JK paper mills effort on flyash management. *Ecovision*, **2004,** 3: 23-25.

[2] Trivedi S. The characteristics of flyash and its usage. Proceedings of Seminar on Ash Utilization, NTPC, Korba, **1993**, 23-27.

[3] Ramgopal. Environmental management practices in NTPC. Proceedings of Seminar on Ash Utilization. NTPC, Korba, **1993**, 110-121.

[4] Jadon VK, Bhalla RK. ISGEC. Flyash brick plants: A profile. Proceedings of Seminar on Ash Utilization, NTPC, Korba, **1993**, 100-109.

[5] Prasa, BJ, Pandey SN. Natural plant succession on the rehabilitated bauxite and coal mine overburdens of Madhya Pradesh. *J Trop Forensic*, **1985**, 1: 309-319.

[6] Dwivedi A, Jain MK. Fly ash – waste management and overview: A review. *Recent Research in Science and Technology*, **2014**, 6: 30-35.

[7] Chakrabarty AK, Anand S, Kaul M. Dry ash collection, handling and disposal. Proceedings of Seminar on Ash Utilization, NTPC, Korba, **1993**, 58-66.

[8] Maiti SS. Evaluation and utilization of flyash as useful material in agriculture. Ph.D. Thesis. Calcutta University, **1993**, 1-77.

[9] Sharma S, Fulekar MH, Jayalakshmi CP. Flyash dynamics in soil water systems. *Critical Reviews in Environmental Control*, **1989**, 19: 251-275.

[10] NTPC Publication. NTPC guide for users of coal ash. NTPC, Noida, **2003**.

[11] Chang AC, Lund LJ, Page AL, Warneke J E. Physical properties of flyash amended soils. *J Environ Qual*, **1977**, 6: 276-290.

[12] Adriano DC, Page AL, Elseewi AA, Chang AC, Straughan I. Utilization and disposal of flyash and other residues in terrestrial ecosystems: A review. *J Environ Qual*, **1980**, 9: 333-343.

[13] Rees WJ, Sidrak GH. Plant nutrition on flyash. *Plant Soil*, **1956**, 8: 141-159.

[14] Abernathy RF. Spectrochemical analysis of coal ash for trace elements. Investing. 7281. U.S. Department of Interior, Washington, D.C, USA, **1969**.

[15] Martens DC, Schnappinger MG Jr, Zelazny LW. The plant availability of potassium in flyash. *Soil Sci Soc Am Proc*, **1970**, 34: 453-456.

[16] Doran JW, Martens DC. Molybdenum availability as influenced by application of flyash to soil. *J Environ Qual*, **1972**, 1: 186-189.

[17] Natusch DFS, Bauer CF, Matu-Siewica A, Evans CA, Baker J, et al. Characterization of trace elements in flyash. *Int Conf Heavy Metals Environ, Toronto*, **1975**, Pp: 553-576.

[18] Kaakinen JW, Jorden RM, Lawasani MH, West RE. Trace element behaviour in coal fired power plant. *Environ Sci Technol*, **1975**, 9: 862-867.

[19] Bern J. Residues from power generation: Processing, recycling and dispersal. In: Land application of waste materials. Soil Conserv Soc Am Ankeny, Iowa, **1976**, Pp: 36-42.

[20] Furr AK, Parkinson TF, Hinrichs RA, Van Champan DR, Bache CA, et al. National survey of elements and radio activity on flyash: Absorption of elements by cabbage grown on flyash soil mixture. *Environ Sci Technol*, **1977**, 11: 1194-1201.

[21] Page AL, Bingham FT, Lund LJ, Bradford GR, Elseewi AA. Consequences of trace element enrichment of soils and vegetation from the combustion of fuels used in power generation. *S Calif Edison Res and Dev Ser*, **1977**, 77-RD-29.

[22] Page AL, Elseewi AA, Straughan I. Physical and chemical properties of flyash from coal fired power plants with reference to environmental impacts. *Residue Rev*, **1979**, 71: 83-120.

[23] Phung HT, Lund LJ, Page AL, Bradford GR. Trace elements in flyash and their release in water and treated soils. *J Environ Qual*, **1979**, 8: 171-175.

[24] Evans D, Giesy J. Pergamon Press Ecol Coal Res. Devpur RF, Wali M. (edtr), New York, **1979,** 782-790.

[25] Crecelius EA. Trace elements leachability from flyash in seawater. *Marine Chem*, **1980**, 8: 245-250.

[26] Environmental Protection Agency Report. Element flow in aquatic systems surrounding coal fired power plants. **1980**.

[27] Elseewi AA, Page AL, Doyle CP. Environmental characterization of trace elements in flyash. In: Trace substances in Environmental Health. Proceedings of Symposium, University of Missouri, Columbia, **1982.**

[28] Fulekar MH, Naik DS, Dave JM. Heavy metals in Indian coals and corresponding flyash and their relationship with particle size. *Int J Environ Stud*, **1983**, 21: 179-182.

[29] Maiti SS, Mukhopadhyay M, Gupta SK, Banerjee SK. Evaluation of flyash as a useful material in agriculture. *Ind Soc Soil Sci*, **1990**, 38: 342-344.

[30] Singh VK, Singh JS. Environmental degradation of Obra-Renukoot-Singrauli area and its impact on natural and derived ecosystem. Technical Report, BHU, India, **1988**, 22-45.

[31] Jain A, Kashyap MK, Banerjee SK. Utilization of flyash for growing tree species. In: Proceedings of "Training cum seminar on eco-rehabilitation of stress sites. TFRI, Jabalpur, **2001**, 1-36.

[32] Lee RE Jr, Crist HL, Riley AE, Maclead KE. Concentration and size of trace metal emission from a power plant. *Environ Sci Technol*, **1975**, 9: 643-647.

[33] Klein DH, Andren AW, Carter JA, Emery JF, Feldman C, et al. Pathways of thirty-seven trace elements through coal fired power plants. *Environ Sci Technol*, **1975**, 9: 973-979.

[34] Anderson WL, Smith KE. Dynamics of mercury at coal fired power plant and adjacent coaling lake. *Environ Sci Technol*, **1977**, 11: 75-80.

[35] Zoller WH, Gladney ES, Duce RA. Atmospheric concentrations and sources of trace metals at the South Pole. *Science*, **1974**, 183: 198-200.

[36] Thesis TL, Westrick JD, Hsu CL, Marley JJ. Field investigation of trace metal in ground water from flyash disposal. *J Water Poll Control Federation*, **1978**, 2457-2469.

[37] Swaine DJ. Trace elements in flyash. *DSIR Bull*, **1977**, 218.

[38] Davidson RL, Natusch DFS, Wallace JR, Evans, CA Jr. Trace elements in flyash dependence of concentration of particle size. *Environ Sci Technol*, **1974**, 8: 1107-1113.

[39] Quann RJ, Neville M, Janghorbani M, Mims CA, Sarofin AF. Mineral matter and the trace element vaporization in a laboratory pulverized coal combustion system. *Environ Sci Technol*, **1982**, 16: 776-781.

[40] Dreesden DR, Gladney ES, Owens JW, Pekins BL, Wienke CLet al. Comparison of levels of trace elements extracted from flyash and levels found in effluent waters from a coal fired power plant. *Environ Sci Technol*, **1977**, 11: 1017-1026.

[41] Vaccarino C, Cimino G, Tripodo MM, Lagana G, Logindice L et al. Leaf and fruit necroses associated with vanadium-rich ash emitted from a power plant burning fossil fuel. *Agric Ecosys Environ*, **1983**, 10: 275-284.

[42] Evans DW, Weiner JG, Hoton JH. Trace elements input from a coal burning plant to adjacent terrestrial and aquatic environments. *J Air Poll Cont Ass*, **1980**, 30: 567-573.

[43] Crockett AB, Kinmison RR. Mercury residues in soil around a large coal fired power plant. *Environ Sci Technol*, **1979**,13: 712-715.

[44] Klein DH, Russel P. Heavy metals: Fall out around a power plant. *Environ Sci Technol*, **1973**, 7: 357-358.

[45] Bunz K, Rosner G, Schmidt W. Distribution of lead, cobalt and nickel in the soil around a coal fired power plant. 2 Pflazenernaehr. Bodenkd, **1983**, 14: 705-713.

[46] Dassler HC, Bortiz S. Air pollution and its influence on vegetation causes/effects/prophylaxis and therapy. Dr. W Junk Publishers, Dordrecht, **1988**, 169-188.

[47] Martins MH, Coughtrey PJ. Impact of metals on ecosystem function and productivity. In: Effect of heavy metal pollution on plants, Lepp NW (edtr) Applied Science Publishers, London, **1981**, 119-158.

[48] Van Craen MJ, Denoyer EA, Natusch DFS, Adams P. Surface enrichment of trace element in electric steel furnace dust. *Environ Sci Technol*, **1983**, 17: 435-439.

[49] Murray F. Effect of sulfur dioxide on three Eucalyptus species. *Aust J Bot*, **1984**, 32: 139 - 145.

[50] Chamel A, Garrec JP. Penetration of fluoride through isolated pear leaf cuticles. *Environ Poll*, **1977**, 12: 307-310.

[51] Banerjee SK, Kashyap MK, Manjhi RB. Characteristics and environmental impact of flyash. TFRI Publication, Jabalpur, **1998**, 37.

[52] Furr AK, Kelley WC, Bache CA, Gutenmann WH, Lisk DJ. Multi elements uptake vegetable and millet grown in pots on flyash amended soil. *J Agric Food Chem*, **1976**, 24: 885-888.

[53] Straughan IR, Elseewi AA, Page AL. Mobilization of selected trace elements in residues from coal combustion with special reference to flyash. In: Trace substances in environmental health. XII. Symposium Uni Missouri, Columbia, **1978**, 389-402.

[54] Allaway WH. Agronomic controls over the environmental cycling of trace elements. *Adv Agron*, **1968**, 20: 235-274.

[55] Mulford FR, Martens DC. Response of alfalfa to boron in flyash. Soil. *Sci Soc Am Proc*, **1971**, 35: 296-306.

[56] Elseewi AA, Bingham FT, Page AL. Growth and mineral composition of lettuce and Swiss chard grown on flyash-amended soil. Environmental Chemistry and Cycling Processes Conf, Springfield, Virginia, **1978a**, 568-581.

[57] Phung HT, Lund LJ, Page AL. Potential use of flyash as a liming material. Environmental Chemistry and Cycling Processes. In: DOE Symposium US Department of commerce, Adriano DC, Brisbin IL Jr (edtrs.), Springfield, Virginia, **1978**, 509-515.

[58] Adriano DC, Woodford TA, Ciravolo TG. Growth and elemental composition of corn and bean seedlings as influenced by soil application of coal ash. *J Environ Qual*, **1978**, 7: 416-421.

[59] Townsend WN, Hodgson DR. Edaphological problems associated with deposits of pulverized fuel ash. In: Ecology and Reclamation of Devastated Land, Hutnik RJ, Davis G (edtrs.), Gordon and Breach, London, **1973**, 454-456.

[60] Cope F. The development of a soil from an industrial waste ash. *Int Soc Soil Sci Com*, **1962**, 859-863.

[61] Elseewi AA, Page AL, Grinm SR. Availability of sulfur in flyash to plants. *J Environ Qual*, **1978b**, 7: 69-73.

[62] Gupta GMC, Ghose AKM. The effect of smoke pollutants on the leaf epidermal architectural in *Solanum melongena* L. variety *Pusa purple* long. *Environ Pol*, **1986**, 41: 315-325.

[63] Merakchiska-Nikolova M, Karnenove-Vakhimenko S, Chuldzhiyan Kh. Effect of thermal power emission on tobacco and corn plants. **Fiziol Rast**, **1985**, 11: 66-71.

[64] Stemple RB, Tryon EH. Effect of coal smoke and resulting flyash on site quality and redial increment of white oak. Castanea. **1983**, 38: 396-406.

[65] Smith WH. Air pollution and forests: Interaction between air contaminants and forest ecosystems. Springer-Verlag, New York, **1981**.

[66] Foil JLA, Wochok ZS. Soybean growth on flyash amended strip mine spoils. *Plant Soil*, **1977**, 48: 473-484.

[67] Kovacic W, Hardy RG. Progress report: Utilization of flyash in the reclamation of mine spoils banks in south eastern Kansas. *Geol Surv Bull*, **1972**, 204: 29-31.

[68] Capp JP, Engle CF. Flyash in agriculture. Bur. Mines Inf. Cir. 8348: U.S. Dept. Interior. Washington, D.C, USA, **1967**, 210-220.

[69] Martens DC. Availability of plant nutrients in flyash. *Compost Sci*, **1971**, 12: 15-18.

[70] Banerjee SK, Kashyap MK. Distribution of microorganisms in different aged flyash dykes in relation to vegetation development. *J Environ Stud Pol*, **1999**, 2: 117-124.

[71] Banerjee SK, Singh AK, Jain A, Bhowmik AK, Manjhi RB, et al. Pollution absorbing efficiency of tree species in industrial area. Final report: Flyash Project. TFRI Publication, Jabalpur, **2001a**, 80-84.

[72] Banerjee S, Singh AK, Banerjee SK. Impact of flyash on foliar chemical and biochemical composition of naturally occurring ground flora and its possible utilization for growing tree crops. *Ind For*, **2003**, 129: 964-978.

[73] Banerjee SK, Singh AK, Jain A, Bhowmik AK, Manjhi RB, et al. Pollution absorbing efficiency of tree species in industrial area. Final report: Flyash Project. TFRI Publication, Jabalpur, **2001b**, 85-89.

[74] Mishra AK, Mishra TK, Manjhi RB, Biswas SC, Banerjee SK. Spoil characteristics and vegetation development in different aged flyash dykes of Chacahi (MP) thermal power plants. *Ind J For*, **1997**, 20: 362-368.

[75] Odum PE. Basic ecology. Saunders College Publishing. Holt-Sounders, Japan, **1983**.

[76] Mc Naughton SJ. Relationship among functional properties of California grassland. Nature, **1967**, 216: 168-169.

[77] Singh RK, Pawar SK, Pandey AK. Biological reclamation of flyash. J Trop For, **1992**, 8: 34-38.

[78] Mishra AK, Williams AJ, Bhowmik AK, Banerjee SK. Performance of different NFT and non-NFT species on flyash. *Environ Ecol*, **1995**, 13: 920-923.

[79] Banerjee SK, Gupta BN. Biological reclamation of mined out land. TFRI series IV, Jabalpur, **1996**.

[80] Technology Information, Forecasting and Assessment Council, Department of Science & Technology, Government of India.

[81] Report on fly ash generation at coal/lignite based thermal power stations and its utilization in the country for the year 2014-2015. Central Electricity Authority, New Delhi, **2015**.