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Review Article

Coal Fly Ash: Some Aspects of Characterization and Environmental Impacts

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Abstract: Environmental pollution due to non-biodegradable materials mainly inorganic fractions are matter of concern since last two decades. Industrialization and urbanization are the two phenomena that are going unabated all over the world. Apart from the needs for these phenomena, one has to look into their negative impacts on the global environment and social life. Most important ailing effect of these global processes has been the generation of large quantities of industrial wastes. Major non-degradable pollutants of thermal power plants are heavy metals present in ash. Arsenic, barium, copper, molybdenum and zinc are normally present in fly ash, besides these lots of other metals are also present in traces such as Ag, Al, As, Ca, Cd, Co, Cr, Cu, Fe, Mg, Hg, Mn, Mo, Ni, Pb, Se, Sn, Sr, Zn, etc. Therefore, the problems related with their safe management and disposal has become a major challenge. Second associated problem is the pressure on land, materials and resources to support the developmental activities, including infrastructure. Electricity generation in India predominately depends upon coal based power plant for a couple of coming decades. Coal based power plant requires coal of high calorific value to generate optimum heat consequently to generate electricity, in this process a by product is generated which is a waste material and named as fly-ash or coal ash. Current annual production of fly ash, a by-product of coal based thermal power plants (TPPs), is 120 million tonnes (MT). At present, the disposal of generated fly ash is by either wet disposal or dry disposal. Some of the problems associated with fly ash are land required for disposal and toxicity associated with heavy metals leached to ground water. This review presents characteristic of fly ash and some aspects of its environmental impacts.

Keywords: Thermal power plants, Fly ash, Heavy metals, Leaching, Environmental impacts.

INTRODUCTION

Thermal power plant generates large amounts of fly ashes which contain toxic metals and environmental risks associated with this coal fly ash during wet storage in the ash ponds¹. The disposal of coal fly ash subjects these metal rich materials to conditions that may result in further sequestration of the metals or to their release to the environment². The release and transport of trace metals from coal fly ash material is an area of environment concern because of the wet storage in the ash ponds³. The volatilization, melting, decomposition and the formation of new materials and oxidation are the main mechanisms to transfers the metals from coal to fly ash⁴. The major potential impacts of fly ash disposal either in ash pond or reused in the cement industry leads to leaching of potentially toxic substances into soils, surface water and groundwater. Environmental concerns regarding the potential contamination of soil, surface and ground water due to the presence of soluble metal species in the ash pond leachate is of great concern⁵.

The soluble salt content in ashes is closely related to the coal properties and the age of the fly ash and also to the pH and other environmental conditions⁶. When fly ash interacts with water the principal process affecting the leaching process are dissolution of primary solids and precipitation of secondary solids as well as redox conditions, sorption and hydrolysis reactions⁷. Leaching tests are used as tools to estimate the release potential of constituents from fly ash over a range of possible waste management activities, including during recycling or reuse, for assessing the efficacy of waste treatment processes, and after disposal⁸. The wet disposal of the fly ash into the ash ponds caused leaching of constituents from fly ash due to weathering. Some metals concentration is increased due to leaching of constituents from fly ash particles⁹. The continuous long term leaching experiments were carried out with the 3.4 kg of fly ash was suspended in 17 L of deionised water to simulate the ash ponding environment¹⁰. An 18 month survey was done to assess the environmental impacts of the Tennessee Valley Authority (TVA) coal ash spill in Kingston, Tennessee in 2008 to demonstrated the leaching experiments on the spilled TVA coal ash which revealed that leachable coal ash contaminants, particularly arsenic, selenium, boron, strontium and barium had different effects on the quality of impacted environments and the EPA has proposed regulations to manage coal ash disposal¹¹⁻¹³.

Ash pond releases are an environmental concern due to the potential leaching of toxic metals and metalloids from the ash to the water and the subsequent discharge of waters from the ponds. Numerous studies have examined the leaching potential of Se and As from fly ash due to their solubility and toxicity¹⁴⁻¹⁶. Metal mobility is controlled by the dissolution of primary solids and precipitation/sorption reactions. Class C fly ash has high calcium content and therefore alkaline conditions, which for adsorption reactions favour arsenic and selenium release from the fly ash¹⁷. Chemical characterization of solid waste can be determined using sequential extraction procedures. Such experiments are shown that arsenic and selenium leaching from alkaline fly ash was controlled by a calcium phase¹⁸⁻¹⁹. More than 65000 acre of land in India is occupied for storage of fly ash in ash storage ponds which is leading to the wide spread contamination of soil as well as surface and groundwater²⁰. The purpose of characterization of the ash basins waters of the thermal power plants can help identify constituents of concern from an environmental perspective²¹.

Characterization: Fly ash particles are very fine solid spheres with different chemical composition. Characteristics of fly ash depend on the coal used for its generation in thermal power plants. As the characteristics may differ even for particles in a given ash, characterization becomes important before any suggestion for its use. The following sections deals with several aspects of fly ash characterization.

CLASSIFICATION OF FLY ASH

It is not very easy to classify a complex material such as fly ash through limited parameters. Joshi and Marsh²² studied the physical, chemical and mineralogical properties of some Canadian fly ashes and could not find a characterization parameter exclusively relating to the coal type though reactivity of the ash seemed to increase with its surface area. Kempaska²³ classified the fly ashes according to the type of coal, furnace design and chemical composition. Roy and Griffin²⁴ proposed a classification system along with nomenclature for coal fly ash based on chemical composition, hydration pH and particle size distribution. Cereda *et al.*²⁵ observed that particles in fly ash could be grouped into several classes depending on the matrix as well as trace element composition. Watt²⁶ studied the characteristics of different fossil-fuel types of fly ash (coal, oil, peat, brown coal and oil shales) and observed the generation of large amounts of clinkers and fly ash during combustion; considerable amounts of gypsum and scrubber water were produced in flue gas cleaning and the amount of residue depended on the ash content and the sulphur content of the fuel.

McCarthy *et al.*²⁷ assembled a database of chemical, mineralogical and physical characteristics of North American fly ashes for utilisation and modelling their behaviour after disposal. Dudas and Warren²⁸ presented a submicroscopic model of fly ash particles. Howers *et al.*²⁹ studied fly ashes from 21 Kentucky power plants by grouping them according to the sulphur content of the feed coal. De Luxan *et al.*³⁰ characterised the fly ashes produced by thermoelectric power plants in Spain by physical, chemical and mineralogical properties. Furuya *et al.*³¹ fractionated fly ash samples using nylon sieves and observed that size, density, element and morphological distribution gave insight into the softening property of ash, combustibility of coal, and coal combustion conditions. Mukai *et al.*³² characterised a submicron coal ash chemically after density separation. Lu *et al.*³³ characterised a chemically modified fly ash by particle size distribution, valence of surface elements, surface topography, dispersion in an organic medium and affinity for water. Kosuge *et al.*³⁴ classified fly ash into different groups on the basis of solubility in HCl solution. Rose³⁵ characterised fly ash with respect to its inorganic ash sphere (IAS) to spheroidal carbonaceous particles (SCP) ratio. ASTM C618³⁶ specified two categories of fly ashes depending on the type of coal and the resultant chemical analyses.

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 (SO₄) contents are generally higher in Class C fly ashes.

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 20% 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 chemical activator such as Sodium Silicate (water glass) to a Class F ash can lead to the formation of a geopolymer.

Notwithstanding the ASTM classification, based on the boiler operations further classified fly ash with two distinct categories: Low temperature (LT) fly ash: Generated out of combustion temperature below 900 °C. High temperature (HT) fly ash: Generated out of combustion temperature above 1000 °C. This threshold temperature demarcates the development of metakaolinite phases in the case of LT and the same constituents form as reactive glassy phases in the case of HT fly ash. LT fly ash is more reactive at early ages hence preferred for precast building materials such as bricks/blocks.

MORPHOLOGY AND STRUCTURE

Zwozdziak *et al.*³⁷ determined the size, shape, structure and mineralogical composition of fly ash using transition electron microscopy, electron diffraction and XRD. Miwa *et al.*³⁸ used a secondary ion mass spectrometer, X-ray micro-analyser and SEM to investigate the surface characteristics and depth profile of a coal fly ash. The results of ion microprobe depth profiles and X-ray imaging of elements on spattered surfaces of fly ash particles showed fairly good agreement. Small and Zoller³⁹ used the SEM technique to provide information on particle shape and origin, sample homogeneity and elemental composition which was not available from bulk analysis. SEM studies of Kawfherr and Lichtman⁴⁰ indicated similarities in submicron- and micron- sized particles of fly ash, both were spherical and contained Si, Al, K, Te, Ti, and S as the main components. Sun *et al.*⁴¹ investigated the morphology of pulverised fly ash (PFA) through SEM and observed three kinds of particles: spherical, irregular, fused and porous carbon. Of these the spherical and irregular-fused PFA are of good quality and are suitable for cementitious building materials.

Structure Bellotto *et al.*⁴² suggested XRD and Raman microfocus spectroscopy for structural characterisation. McCarthy *et al.*⁴³ used XRD while identifying the crystalline phases: quartz, periclase, ferrite spinel, anhydrite and lime in fresh ash as well as in ash buried 12 years before. Van Roode *et al.*⁴⁴ suggested using the XRD technique for the quantitative measurement of quartz, mullite, magnetite and haematite and the glass content by difference. Using XRD White and Case⁴⁵ found mullite and silica as the major crystalline phases in fly ash. Mings *et al.*⁴⁶ developed techniques for the quantitative determination of the crystalline composition of fly ash by X-ray fluorescence and diffraction. These methods were fast, accurate and provide explanations of the behavioural characteristics of fly ash. Zelechower *et al.*⁴⁷ used EPMA and XRD techniques for determination of the phase composition of fly ashes. McCarthy and Solem⁴⁸ applied a protocol for semi-quantitative XRD analysis of fly ash in studies of the typical mineralogy of high- and low-calcium samples, the consistency of sample mineralogy from a typical power station, the partitioning of chemical constituents into crystalline phases, and crystalline phases relevant to the use of fly ash in concrete.

Elemental analysis: Furuya *et al.*⁴⁹ studied a coal fly ash for elemental characterisation by spectrophotometry, ICP and SEM-energy dispersive X-ray analysis. Valkovic *et al.*⁵⁰ analysed fly ash using X-ray emission spectrometry. Oishi⁶⁷ analysed the fly ash for Zn, Co, Cr, Ni, Na, K, Mg, etc using ICP optical emission spectroscopy. Bellotto *et al.*⁴² suggested PIXE and proton-induced gamma-ray emission for bulk elemental analyses, and X-ray photoelectron and Auger spectroscopy for surface elemental analyses. Sadasivan and Negi⁵¹ used energy dispersive X-ray fluorescence to analyse major and minor trace elements in fly ash from coal-fired thermal power plants in India. The ash/coal ratios for various elements indicate that most are enriched, except for sulphur, which was depleted. Torok *et al.*⁵² collected fly ash samples from Hungarian brown coal fuel power stations both before and from the electro filter as well as the chimney to examine as bulk or individual microscopic particles using different X-ray emissions methods; the toxic metal content in chimney ash was much higher than that of the filter ash. Beckwith⁵³ discussed the advantages and limitations of the analysis of coal fly ash by inductively coupled plasma atomic emission spectroscopy. Zelechower *et al.*⁴⁷ used the EPMA and XRD techniques for the determination of chemical composition of fly ashes.

Mings *et al.*⁴⁶ found that X-ray fluorescence and diffraction methods for the quantitative determination of elemental composition of fly ash were fast, accurate and provide explanations of the behavioural characteristics of fly ash. Mishra *et al.*⁵⁴ developed a rapid X-ray fluorescence method for the routine analysis of fly ash to give matrix core values comparable to the wet chemical method. Neutron activation analysis studies by Hart *et al.*⁵⁵ indicated significant enrichment of all elements except Br in the fly ash relative to the coal, which contained 35% ash. Nerin *et al.*⁵⁶ critically

evaluated the digestion of fly ash using concentrated acids including HClO_4 , HF and HNO_3 for the analysis of As, Fe and Mn by atomic absorption spectrophotometry. Jojo *et al.*⁵⁷ used the fission track technique to activate the uranium present in fly ash. McCarthy *et al.*⁵⁸ investigated a western fly ash by XRD and found higher CaO.MgO.SO_3 contents and lower $\text{Al}_2\text{O}_3.\text{SiO}_2$ contents compared with the eastern bitumen fly ashes. Seaverson *et al.*⁵⁹ used thermal desorption spectrometry (TDS) and FTIR photo acoustic spectroscopy techniques in combination to identify the water and -OH groups associated with four fly ashes. TGA data indicated that the loss-on-ignition in many of the ashes was not entirely due to the presence of unburned carbon.

Available form of heavy metals: Bioavailable fraction of a metal is the most toxic form of heavy metal⁶⁰ because this fraction is generally absorbed by plants and enters the food chain. The plant available metal has been assessed by using various extracting media.^{61, 62} Diethylene triamine penta acetic acid (DTPA) commonly used to measure plant available trace elements in soils^{63, 64} found 50% of the cadmium from the soil is available for Corn seedlings. Higher concentration of DTPA extracted Cd and Pb than Cu, Cr, Ni and Zn was observed by Sawhney and Frink^{65, 66} has reported that, of the metals present in soil only small amount i.e. < 7% is taken up by the vegetation.

Methods of ash disposal: Two methods of disposal are being used, viz. dry disposal and wet disposal.⁶⁷ Dry disposals involve simply collection of ash in the bottom of hoppers of the mechanical and electrostatic precipitators⁶⁸. It is then taken through closed wagons or bags to disposal sites. Through, this is continuous system, its application is limited. While wet disposal system involves sucking of fly ash from the dust collectors. Converting it to slurry in proportion of 60% water to 40% ash and then discharging it to the dumping area/disposal pond through pipe lines.

In India, slurry is being disposed of on open ground or in ponds, and by landfilling. In developed countries landfilling, ponding, mine disposal⁶⁹ and discharge in ocean are common practices.⁷⁰

Disposal of ash to landfill sites raises a number of issues regarding its subsequent impact on the local environment⁶⁸. There are basically two stages in which ash based components might be mobilised to enter ground and surface waters:-

- (i) Leaching of the solution during hydraulic transport to lagoons.
- (ii) In-situ leaching of ash after disposal.

In developed countries discharge of ash is only permitted when its characteristic can be shown to fall within the limits of consent granted by the appropriate regulatory authority, while in India such standards are seldom adhered to during ash dumping.

PROBLEMS POSED BY FLY ASH

Bottom and fly ash produced by thermal power plants constitute nearly 31.72% of the quantity of coal consumed. Fly ash can travel up to 40 to 50 km in the down wind direction. It settles down subsequently causing land degradation, severe air and water pollution and disease in plants and animals, including human being. Obnoxious gases (viz. CO_2 , SO_2 , NO_x and hydrocarbons) when coming in contact with fly ash, result into synergistic ecological chemical reactions which affect the fauna and flora in the adjoining region. Dust bowl conditions are invariably created in dry weather around the stack by which the nearby aquatic bodies often become murks at best and flaccid at worst during excessive humid period⁷¹. The discharge of fly ash into lakes, rivers or ash bunds by inland stations and into the sea by coastal power stations disturb the ecology of the region.

Air pollution due to fly ash: Fly ash produced during combustion of coal depends on the ash content in coal. Percentage of ash content in coal during this period has increased from 30-35% to 40-45%

and even more in certain cases ⁷² due to the poor quality of coal produced in the country. Several estimates suggest that the fly ash released into the atmosphere appears to be about 5 to 10% of the total ash in coal, and the solid waste generated in the form of ash after the combustion of coal is about 25% to 30%. The presence of toxic trace metals in the fly ash particulates constitutes the greatest health hazard. Metals account for only 0.01% to 0.3% of all particulates in air, but their significance may be for greater due to their accumulation and possible synergistic effects in human tissue. Fly ash pollution at the coal based power plants is found within the house, and particulates which are spewed out of the chimney, can be carried by Wind for several miles ⁷³ leaving in its wake a thin carpet of black particles on roads, trees, house, agricultural land, water system and even affects animals, vegetation, materials and ecology.

Fly ash particulates vary from 0.1 micron to greater than 100 microns. The inverse relationship between fly ash particulate size and trace elements has been observed ^{74, 75}. Due to the increased concentration of toxic trace elements in finer fly ash particulates small particulate escaping emission stacks will have greater biological impacts. Depending on size of fly ash particulate, particles will be trapped in the mucous layer or in the alveoli. For particulate aerosols the position is more complex. Particles of 1.0 microns diameter or more tend to be deposited but only those less than about 7.0 microns deposit in the conductive airways. Particles less than 0.1 microns deposit in the alveoli's. Most of the particles between 0.1 and less than 0.1 microns size are exhaled. However, the pattern and depth of inhaled materials may alter the deposition of particles.⁷⁶ Inhalation of toxic metals is more harmful than ingestion by way of food or water.

Impact on water system: By using control devices like scrubbers, mechanical and electrostatic precipitators etc., fly ash from the stack of coal based power plants can be removed to the extent of 98 to 99.5%. Since there is no consistent trend of effective utilization of fly ash, the stock piles of fly ash will continue to grow as reliance upon coal as a fuel source increases. At present an estimated 8.14 million tonnes fly ash produced in a year is disposed of in dry and wet methods. In a dry method, fill or dumping of fly ash on low laying area is practiced. In a wet method, fly ash is mixed with water and discharged the ash laden water into impounded ponds, lagoons, rivers or the sea.

The dry dumping of fly ash in open beds or in land fill area keep the fly ash vulnerable to the action of rain water and winds. Strong winds can move particles of fly ash from dump sites to adjacent agricultural lands/food stuff or surfaces, drinking water bodies. Since less than 10% of fly ash constituents are considered water soluble at any times, surface association of toxic metals on fly ash can be a major source of water pollution. ⁷⁷ The actual amount of toxic elements released from fly ash in natural water (pH 7 to 8.5) from stock piles of fly ash depends largely on the pH, bonding between the element and fly ash, its chemical form and the physicochemical properties of water.⁷⁸

It has been observed that a pH decrease 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 may bring some of the trace element in water by means of chelation and complexation reactions.⁷⁹ Fly ash leaching experiment carried out at pH 4, pH 5, pH 6, pH7, pH 8 and pH 9 slurries demonstrates that pH regulates the leaching process, and the fly ash leaching was increased with decreasing pH, while sorption capacity increased with increasing pH; but the total (final) soluble quantity of toxic metals was dependent upon final attained pH of the fly ash slurries.⁷⁶ Studies conducted ^{80, 81} on trace elements content at different depths of fly ash bed indicates that acidic rain fall on such disposal sites mobilizes toxic metals in higher concentration and changes the quality of surface and ground water table by leaching and percolation. Similar study conducted at different fly ash bed depths in a dry ash pond demonstrates that the lagooned ashes are virtually saturated with water and they would percolate quickly. It has been observed that the mobilization of

fly ash constituents were influenced by various environmental factors such as leaching, percolation, pH, age of ash, ion exchange, precipitation, sorption, deposition and transformation, and need to be studied in details. In spite of the existing water quality standards, there are several constraints in implementing the guidelines. As such, there are not direct regulations on the disposal of ash into the water system. It becomes important to critically evaluate the impact of ash characteristics on the physico-chemical properties of water, the movement of trace elements in food chain, and its health impacts. Ash pond is the most preferred procedure of fly ash disposal, although dumping in flowing waters, lagoons and marine seas is also practiced.⁸² The quantity of ash would determine the size and design of the pond. There are two major problems associated with the disposal of ash in ponds:

- a. Acidic or alkaline nature of ash pond waters, quantities of suspended solids, and the trace metals on the effluents discharged to surface streams and
- b. Sedimentation of fly ash and leaching of trace metals from fly ash to ground water.

In fly ash disposal basins, the elements are left to land for several months and thus results into:

- a. Continuous discharge of ash effluents and their long settling period lead to settling of fly ash particles.
- b. Release of large quantities of chemical constituents in water including potentially toxic heavy metals.

Ash disposal basin is of pronounced importance because availability of the elements can influence their entry into the food chain of aquatic life.^{83, 84} The disposal of ash effluents along stream bed flow into the river offer greater scope of dilution of pollutants, depending upon the volumes of water used for disposal. In a river with year round flow, the discharge of ash effluents may pose significant problems in terms of its likely effect on the biota at the point of disposal.⁸⁵

Fly ash released in water-soil system by way of disposal in dry and wet methods are ultimately incorporated in biogeochemical cycles.^{86, 87, 88} The metabolic activity of microorganisms plays a significant part in the mobility of toxic elements in the environment. Micro-organisms are exceedingly versatile in the way they metabolize natural substances, and if they do not degrade a particular compound, then it is likely that higher organisms will have the capacity to do so. A study of microbial inter conversions of toxic compounds can contribute substantially to environmental science. Once the method is introduced into a microbial ecosystem, each formal valence state of that method is available for chemical or biochemical reactions.⁸⁶

The biochemical process of methylation of heavy metals and metalloids have received considerable attention in recent years.⁸⁹ Methylation is believed to be a detoxification mechanisms for converting toxic ions to a more volatile form that will be released to the atmosphere. Several microbial species are capable of performing this transformation in soils and sediments under both aerobic and anaerobic conditions. Methylation forms of trace metal are frequently more toxic and are more readily adsorbed or absorbed by higher organisms than the inorganic form. Methylation of mercury by microbes in marine and fresh water sediments is the best documented case of this type of biological transformation⁹⁰. As, Fe, Pb and Zn are also examples of other toxic elements that undergo methylation.

Higher organisms including man are capable of affecting biotransformation of hazardous chemicals. Reactions of Cd and metallothioneine in retention of this element in renal tissues have been reported.⁹¹ However, biotransformation of toxic elements in the environment are particularly very important in determining the effect on man and other organisms because the molecular form and biochemistry of these transformed chemicals determine their availability, persistence, bioaccumulation and toxicity.⁹²

Impact on soil system: The problem of soil pollution by constantly settling fly ash particles in the vicinity of coal based power plants differ in a number of important aspects from those of water, or air pollution, especially the polluting fly ash particulate remain in place for relatively long periods of time unless removed or washed away. Soil poisoning occurs either due to the carriage of fly ash by winds to a farther distance or by fallout from the atmosphere by rain. Fly ash is sometimes carried by wind to distances as far as 120 kilometres.⁹³ The most limiting factors in fly ash utilization on land are unfavourable changes in chemical parameters like pH, salinity, and levels of certain trace elements. Most of the coal in the country gives rise to alkaline fly ashes, which have a certain but variable degree of neutralization capacity. It has been noted⁹⁴ that some have a neutralizing capacity equivalent to 20% that of agricultural lime stone, thus making it an excellent limiting material for acidic soils.

Neutralizing capacity of the alkaline fly ash has been adequately reported in the literature.⁹⁵ However, it has been suggested that, due to its relatively short term, low neutralizing capacity and high levels of potentially toxic trace elements, massive fly ash application on agricultural soil may have to be curtailed. Soil salinity and fly ash amendments have been directly correlated by Adriano et al.⁹⁶ Fly ash as an amendment might alter many physical, chemical and biological properties of soils. Although rate of amendments and the initial physico-chemical properties are prerequisites to such changes, alteration in texture, bulk density, moisture-holding capacity, pH, soluble salts content, base saturation, exchange capacity hydraulic conductivity, temperature cohesiveness, erodability and elemental content could be expected.⁹⁶ Column experiment study carried out⁷⁶ to understand the mechanism of leaching of trace elements by the action of acidic rain water on a fly ash/soil bed in a water environment, such as in a land fill area of fly ash disposal sites, indicates that pH regulates the change in available and total metal contents in layers of soils; and found a lower pH with lower total metals and higher available in soil and their release into leachate water were also found to be dependent on organic matter, cation exchange capacity, absorption/precipitation and subsequent mobility of heavy metals in soils in order of importance. The findings also illustrates that the metals content in the leachates water were proportional to the amounts of fly ash applied to the soil bed.

Column experiments,⁹⁷ in which certain heavy metals leach from impounded ash, then enter ground water by percolation through soils, a condition that is prevailing in ash pond, also demonstrates the findings similar to the column experiment set up for land fill area of fly ash disposal sites. It has been found that the Pozzolanic reaction of fly ash is more effective in acidic soils than in neutral or basic soils.^{82,76} At an addition rate of 8% by weight, fly ash increased the soil mixtures water holding capacity⁹⁸ while water holding capacity shows improvement with fly ash amendment. Soil hydraulic conductivity improved at lower rates of fly ash application but deteriorated when the rate of fly ash amendment exceeded 20% in calcareous soils and 10% in acidic soil.⁹⁸ In fly ash is to be considered as a multi-nutrient carrier and soil conditioner, the effects on soil microorganisms must be given due consideration from the soil fertility and productivity point of view. In a pioneering study⁹⁹ on the impact if fly ash on soil microorganisms, it was observed that microbial activity got depressed at lower levels and significantly reduced at higher levels of fly ash application. Plant growth has often shown improvement under fly ash amended conditions but has also been depressed under unsuitable conditions^{100, 101} fly ash alters the physical conditions of the soil and add several trace elements, making it difficult to ascertain the effect of an individual property on plant growth and crop yields. Field and Green house study indicates that fly ash may benefit plant growth.⁹⁸ In coal mine spoil areas; its application is towards correction of soil pH and other physical condition apart from creating a nutrient-rich medium for growth of soil cover like moss. As weathering continues higher plant species may be introduced with agricultural soils, the fly ash amendment is directed towards developing suitable agronomic practices to utilize this enormous waste in a useful manner.

IMPACT OF HEAVY METALS ON HUMAN HEALTH

U.S. Environmental Protection Agency tested water samples after the spill; they found toxic heavy metals including arsenic, which they measured at 149 times the allowable standard for drinking water. Water samples also contained elevated levels of other toxic metals: lead, thallium, barium, cadmium, chromium, mercury, and nickel. the toxic contents of coal ash may vary depending on where the coal is mined, coal ash commonly contains some of the world's deadliest toxic metals: arsenic, lead, mercury, cadmium, chromium and selenium.¹⁰² The most common threat that coal ash poses to public health comes from a less dramatic Scenario: the slow leakage of toxic pollution from disposal sites such as ponds and landfills. Toxic pollution, some of it cancer-causing, can and does escape from some of those sites, according to the EPA¹⁰³. This occurs in a variety of ways, most frequently when coal ash comes into contact with water, allowing toxics to "leach" or dissolve out of the ash and percolate through water. Large quantities of coal ash are "recycled," presenting another potential route of exposure to coal ash toxics. Some countries allow coal ash to be used as structural fill, agricultural soil additive, top layer on unpaved roads, fill for abandoned mines, spread on snowy roads, and even as cinders on school running tracks. These uses may expose coal ash to water, increasing the risk of leaching. Coal ash is also dangerous if inhaled, so some of these forms of recycling may endanger human health from airborne particles, even where no water is involved. It has identified for specific sites at which humans have been exposed to coal ash toxics, whether from drinking contaminated water, eating contaminated fish, or breathing fugitive dust.¹⁰⁴ We summarize here some common toxic contaminants present in coal ash which effects on the human health.

Arsenic: Arsenic produces a variety of adverse health effects. Ingesting very high levels can result in death. Chronic exposure to arsenic in drinking water can cause several types of cancer, including skin cancer, bladder cancer, lung cancer and kidney cancer. Recent studies have linked arsenic ingestion to cardiovascular disease and diabetes mellitus¹⁰⁵. Exposure to lower levels can cause nausea and vomiting, decreased production of red and white blood cells, and cardiovascular effects including abnormal heart rhythm, damage to blood vessels, and damage to the peripheral nervous system. According to the Agency for Toxic Substances and Disease Registry (ATSDR), there is some evidence that in childhood, long-term exposure to arsenic may result in lower IQ scores and exposure to arsenic in the womb and early childhood may increase mortality in young adults¹⁰⁶. Reporting on a study in Taiwan of residents whose well water was contaminated with naturally occurring arsenic, the article found a "significant" trend of increased cases of urinary tract cancer as exposure levels increased¹⁰⁷. In addition to drinking water, arsenic can enter the body via other pathways. Inhaling sawdust from construction with arsenic-treated lumber can greatly increase the danger of lung cancer, as it can be absorbed through the lungs. Inhaling arsenic from coal ash fugitive dust can likewise pose a danger to human health. Arsenic can also be absorbed through the skin, which is why its use in decks and play equipment was outlawed. Children who play near spilled coal ash or where there is fugitive dust may be at risk of arsenic exposure.

Cadmium: Fortunately, oral ingestion of cadmium results in low levels of absorption. The lungs, however, readily absorb cadmium, so inhalation exposure results in much higher levels of absorption. This makes cadmium a potential hazard from coal ash dust, which may be released into the environment when dry coal ash is stored, loaded, transported, or kept in uncovered landfills. Chronic exposure can result in kidney disease and obstructive lung diseases such as emphysema. Cadmium may also be related to increased blood pressure (hypertension) and is a possible lung carcinogen. Cadmium affects calcium metabolism and can result in bone mineral loss and associated bone pain, osteoporosis and bone fractures.

Lead: Health effects associated with exposure to lead include, but are not limited to, neurotoxicity, developmental delays, hypertension, impaired hearing acuity, impaired haemoglobin synthesis, and male reproductive impairment¹⁰⁸. Importantly, many of lead's health effects may occur without overt signs of toxicity. Scientists have long recognized that children are particularly sensitive, with high levels of lead resulting in swelling of the brain, kidney disease, effects on haemoglobin and possible death. Adverse effects in children can also occur well before the usual term of chronic exposure can take place. Children under 6 years old have a high risk of exposure because of their more frequent hand-to-mouth behaviour. It is now well accepted that there is no safe level of lead exposure, particularly for children¹⁰⁹. Harmful levels of lead exposure can result from drinking water contaminated by coal ash and from exposure to coal ash contaminated soils.

Mercury: Mercury has the dangerous capacity to bioaccumulate, or build-up in animal tissue. When mercury leaches from coal ash into the soil or water, it is converted by bacteria into methylmercury, an organic form that can be absorbed by small organisms and the larger organisms that eat them. As it moves up the food chain, the concentration of methylmercury increases. When it has accumulated to high concentrations in fish, this becomes a major pathway for human exposure. Mercury is particularly toxic to the developing nervous system. Exposure during gestation, infancy, or childhood can cause developmental delays and abnormalities, reduced IQ and mental retardation, and behavioural problems. State agencies regularly issue fish consumption advisories to caution women of child-bearing age and children against eating mercury-contaminated fish. The FDA has set a limit for safe consumption of 1 part per million of methylmercury in fish¹¹⁰.

Selenium: Selenium is used by the body in a variety of cellular functions, too much can be harmful, as can too little. The recommended daily intake is 55 to 70 micrograms. Excess selenium intake can occur in both animals and humans living in areas with elevated selenium in the soil. Most grasses and grains do not accumulate selenium, but when an animal consumes plants that do accumulate selenium (some up to 10,000 mg/kg), they can develop a condition called the "blind staggers"¹¹¹. Symptoms include depressed appetite, impaired vision, and staggering in circles. High exposures can ultimately lead to paralysis and death. Humans are susceptible to similar effects as well as additional neurological impacts. Selenium exposure also affects fish, which absorb the metal through their gills or by eating contaminated food sources such as worms. Extremely high levels of selenium have been found to accumulate in fish and amphibians living in coal ash-contaminated waters and wetlands, if they survive exposure to the toxin. As confirmed by laboratory studies, selenium accumulation can cause developmental abnormalities in fish and amphibians and has led to the death of entire local fish populations. Selenium is bioaccumulative, meaning it is passed up the food chain in increasing concentrations, and excessive amounts have been found in water snakes, small mammals, birds and humans.

CONCLUSIONS

The review deals with important aspects of fly ash which is the interesting waste material of this century. The chemical composition, morphology as well as the classification of fly ash depends on coal quality and size distribution of particles though reactivity of the ash seems to increase with surface area. X-ray diffraction and fluorescence are accurate techniques for the quantitative determination of elements which provide us explanations of its behavioural characteristics. Generally all fly ash samples are containing Fe, Al, S, Si and unburned carbon. Fly ash contains macro-nutrients such as N, P, and K and micro-nutrients such as Cu, Zn, Fe, and Mn in sufficient quantity for consideration for agricultural applications. Apart from these it also contains heavy metals like Pb, Hg, As, Cd, Se, Mo, Sc, Ni, V, and Zn in trace quantity. Fly ash can be characterized by cenospheres,

which have spheroidal morphology and a spongy structure leading to many industrial applications. Fly ash is an effective fill for airfields, pavements, and building bricks. Impacts of fly ash on air, land or ground water pollution may be balanced by minimizing its accumulation either by utilizing or subjecting it to a stabilization process. Heavy metals in fly ash, however, can be immobilized by chelating agents. On treatment with water, rapid leaching of most of the trace metals takes place from the surface of ash particles. Alkali treatment of fly ash can be considered safe for its use in refilling of coalmines. Trace metal concentration in the leachate depends on fly ash weight/solution, pH and concentration of the elements. High calcium fly ashes are more hazardous and source of selenium. The impact of fly ash on ground water is mainly dependent on site conditions. Deeper wells are also a possible solution to the ground water problem.

REFERENCE

1. B. Lokeshappa, A. K. Dikshit, D. E. Giammar, Y. Luo, and J. G. Catalano, "Metals in Indian fly ash: a preliminary investigation," presented at the 3rd International Symposium on Global Energy Futures, Washington University, Saint Louis, USA, 2010, October 1-4.
2. B. Lokeshappa, and A. K. Dikshit, "Metals and their leachings in coal fly ash ponds," presented at the National Conference on Environmental Perspectives and Challenges for the 21st Century (EPC-2011), Andhra University, Visakhapatnam, 2011, June 28-29.
3. B. Lokeshappa, and A. K. Dikshit, "Fate of metals in coal fly ash ponds" *International J of Environmental Science and Development*, 2012, **3** (1), 43-48.
4. A.G. Kim, "Leaching methods applied to cub: standard, regulatory and other," in Proc. 15th International Symposium on Management and Use of Coal combustion Products, St. Petersburg, FL, 2003, 1-12.
5. T. Praharaj, M. A. Powell, B. R. Hart, and S. Tripathy, "Leachability of elements from sub bituminous coal fly ash from India," *Environmental International*, 2002, **27**, 609-615.
6. J. Jankowski, C. R. Ward, D. French, and S. Groves, "Mobility of trace elements from selected Australian fly ashes and its potential impacts on aquatic ecosystems," *Journal of Fuel*, 2006, **85**, 243-256.
7. C. Brunori, S. Balzamo, and R. Morabito, "Comparison between different leaching tests for the evaluation of metal release from fly ash," *Fresenius Journal of Analytical Chemistry*, 2001, **371**, 843-848.
8. D. S. Kosson, H. A. Vander Sloot, F. Sanchez, and A. C. Garrabrants, "An integrated frame work for evaluating leaching in waste management and utilization of secondary materials," *Environmental Engineering Science*, 2002, **19**(3), 159-204.
9. A. Ugurlu, "Leaching characteristics of fly ash," *Environmental Geology*, 2004, **46**, 890-895.
10. W. R. Roy, R. A. Griffin, D. R. Dickerson, and R. M. Schuller, "Illinois basin coal fly ashes. 1. Chemical characterization and solubility," *Journal of Environmental Science Technology*, 1984, **18**, 734-745.
11. L. Ruhl, A. Vengosh, G. S. Dwyer, H. Hsu-Kim, and A. Deonarine, "Environmental impacts of the coal ash spill in Kingston, Tennessee: An 18-month survey," *Environmental Science & Technology*, 2010, **44**, 9272-9278.
12. USEPA "Coal Combustion Residuals – Proposed Rule" December 2010, Available: <http://www.epa.gov/wastes/nonhaz/industrial/special/fossil/ccr-rule/index.htm>.
13. USEPA, "National Primary Drinking Water Regulations: Maximum Contaminant Levels" December 2010. Available: <http://www.epa.gov/safewater/contaminants/index.html>.

14. F. E. Huggins, C. L. Senior, P. Chu, K. Ladwig, and G. P. Huffman, "Selenium and arsenic speciation in fly ash from full-scale coal-burning utility plants," *Environmental Science and Technology*, 2007, **41**(9), 3284-3289.
15. A.P. Khodadoust, P. Naithani, T. L. Theis, and I. P. Murarka, "Leaching characteristics of arsenic from aged alkaline coal fly ash using column and sequential batch leaching," *Industrial & Engineering Chemistry Research*, 2011, **50**(4), 2204-2213.
16. T. Wang, J. Wang, Y. Tang, H. Shi and K. Ladwig, "Leaching characteristics of arsenic and selenium from coal fly ash: role of calcium," *Energy & Fuels*, 2009, **23**(6), 2959-66.
17. C. L. Rowe, W. A. Hopkins, and J. D. Congdon, "Ecotoxicological implications of aquatic disposal of coal combustion residues in the United States: A review," *Environmental Monitoring and Assessment*, 2002, **80**(3), 207-276.
18. S. R. Al-Abed, G. Jegadeesan, J. Purandare, D. Allen, "Arsenic release from iron rich mineral processing waste: influence of pH and redox potential," *Chemosphere*, 2007, **66**(4), 775-782.
19. A.G. Kim, "The effect of alkalinity of class F PC fly ash on metal release," *Fuel*, 2006, **85**(10-11), 1403-1410.
20. V. C. Pandey, J. S. Singh, R. P. Singh, N. Singh, and M. Yunus, "Arsenic hazards in coal fly ash and its fate in Indian scenario," *Resources, Conservation and Recycling*, 2011, **55**, 819-835.
21. L. Dorman, J. H. Rogers, and J. W. Castle, "Characterization of ash basin waters from a risk based perspective," *Water Air Pollution*, 2010, **206**, 175-185.
22. R. C. Joshi and B. K. Marsh, "Some physical, chemical and mineralogical properties of some Canadian fly ashes" *Mater Res Soc Symp Proc*, 1987, **86**, 113-125.
23. A. Kempaska, "Polish system for the classification of fly ash and slag" *Energetyka*, 1981, **35**(7-8), 264-265.
24. W.R. Roy and RA Griffin, "A proposed classification system for coal fly ash in multidisciplinary results". *J Environ Qual*, 1982, **11**(4), 563-568.
25. E. Cereda, GMB Marcazzan, M Pedretti, GW Grime and A. Baldacci, "Occurrence mode of major and trace elements in individual fly ash particles". *Nucl Instrum Methods, Phys Res Sect B*, 1995, **104**(1-4), 625-629.
26. J. Watt, "Automated characterisation of individual carbonaceous fly ash particles by computer controlled scanning electron microscopy: Analytical methods and critical review of alternative techniques". *Water, Air, Soil, Pollution*, 1998, **106**(3-4), 309-327.
27. G.J. McCarthy, JK Solem, OE Manz and DJ Hassett, "Use of database of chemical, mineralogical and physical properties of North American fly ash to study the nature of fly ash and its utilization as a mineral admixture in concrete". *Mater Res Soc Symp Proc*, 1990, **178**, 3-33.
28. M.J. Dudas and C.J. Warren, "Submicroscopic model of fly ash particles". *Geoderma*, 1987, **40**, 101-114.
29. J.C. Howers, J.D. Robertson, G.A. Thomas, A.S. Wong, W.H. Schram, U.M. Graham, R.F. Rathone and T.L. Robl, "Characterization of fly ash from Kentucky Power Plants". *Fuel*, 1996, **75**(4), 403-411.
30. M.P. De Luxan, M.I. Sanchez de Rojas and F Soria, "Characteristics of Spanish fly ashe". *Mater Constr (Madrid)*, 1988, **38**, 25-38.
31. K. Furuya, T Kondo and T Kikuchi, "Characteristic comparison of size density fractionated coal fly ash". *Earozeru Kenkyu*, 1993, **8**(2), 131-138.
32. K. Mukai, T. Kikuchi and K. Furuya, "Chemical characterization of density separated submicrometer coal fly ash". *Mikrochim Acta*, 1988, **3**(1-6), 41-56.

33. 33. Y. Lu, J. Zhang, C. Yang, X. Peng and C. Liu, "Change of structure and properties of chemically modified Fly ash". *Chin Sci Bull*, 1995, **40**(18), 1516-1521.
34. 34. K. Kosuge, Y. Hamada and T. Tamagawa, "Solubility of fly ash in HCl acid solution". *Kogai Shigen Kenkyusho Iho*, 1984, **13**(3), 55±62. (in Japanese).
35. 35. N.L., Rose, "Inorganic fly ash spheres as pollution tracers". *Environ Pollut*, 1996, **91**(2), 245-252.
36. 36. ASTM C618 – 08, "Standard Specifications for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete". ASTM international.2008, C 618.
37. 37. J.W. Zwozdziak, R. Jagiello, M. Kowalski, A.B Zwozdziak and A Lisowski, "Identification of coal fly ash particles in ambient aerosols". *Environ Prot Eng*, 1989, **14**(1), 23-37.
38. 38. T, Miwa, K, Kitagawa and M Mizuta, "Characterization of coal fly ash particles". *Nippon Kagaku Kaishi*, 1991,**5**, 439-441. (in Japanese).
39. 39. J.A. Small and WH Zoller, "Single-particle analysis of the ash from the Dickerson coal-field power plant", *NBS Spec Publ*,1997, **5**(464), 651-658.
40. 40. N. Kawfherr and D. Lichtman, "Comparison of micron and submicron Gly ash particles using
41. SEM and X-ray elemental analysis". *Environ Sci Technol*, 1984, **18**(7), 544-547.
42. 41. B. Sun, C Jia and C Shui, "Particle morphology of pulverized fly ash (PFA) and its physical properties". *Guisuanyan Xuebao*, 1982, **10**(1), 64-69 (1982) (in Chinese).
43. 42. M, Bellotto, C Boni, A Caridi, E Cereda, C Chemelli, GM Braga Marcazzan, F Parmiginni, M Scagliotti and B Bellagamba, "Analysis of coal fly ash by bulk and surface characterization techniques", *Mater Res Soc Symp Proc*,1990, 178,45-56.
44. 43. G.J McCarthy, KD Swanson, PJ Schields and GH Groenewold, "Mineralogical controls on toxic element contamination of groundwater from buried electrical utility of solid wastes", Report 1983, W83-04004, OWRT-A-078-NDAK. 67.
45. 44. M. Van Roode, E, Douglas and RT, Hemmings, "X-ray diffraction measurement of glass content in fly ashes and slags". *Cem Concr Res*, 1987, **17**(2), 183-197.
46. 45. S.C White and ED Case, "Characterization of fly ash from coal-fired power plants". *J Mater Sci*, 1990, **25**(12), 5215-5219.
47. 46. M.L. Mings, S.M. Schlorholtz, J.M. Pitt and T. Demirel, "Characterization of fly ash by X-ray analysis method". *Transp Res Rec*,1983, 941, 5-11.
48. 47. M. Zelechower, D. Smolkam, M. Jablonska and A. Dytkowicz, "Determination of chemical and phase composition of fly ashes by combined EPMA and XRD methods". *Mikrochim Acta Suppl (Modern Developments and Applications in Microbeam Analysis)*, 1998, **15**, 207-210.
49. 48. G.J, McCarthy and JK, Solem, "X-ray diffraction analysis of fly ash". II, Results. *Adv X-ray Anal*, 1991, **34**, 387-394.
50. 49. K, Furuya, Y, Miyajima, T, Chiba and T, Kikuchi, "Elemental characterization of particle size-density separated coal fly ash by spectrophotometry, ICP and scanning electron microscopy -energy dispersive X-ray analysis". *Environ Sci Technol*, 1987, **21**(9), 898-903.
51. 50. V, Valkovic, J, Makjanic, M, Jaksic, S, Papovic, AJJ Bos, RD Vis, K, Wiederspahn and H, Verhenl, "Analysis of fly ash by X-ray emission spectroscopy and proton microbeam analysis". *Fuel*, 1984, **63**(10), 1357-1362.

52. 51. S, Sadasivan and BS Negi, "Chemical characterization of fly ash from coal-fired thermal power plants in India". *Sci Total Environ*, 1991, 103(2-3),151-158.
53. 52. S. Torok, S. Sandor, I. Demeter, HQ Le and Z Szokefalvi-Nagy, "Chemical characterization of fly ash samples by synchrotron radiation X-ray fluorescence and other X-ray emission techniques. *Ital Phys Soc*, 1990, **25**, 875-878.
54. 53. Pm, Beckwith, "Analysis of coal fly ash by inductively coupled plasma atomic emission spectrometry: Elem Anal". *Coal Its byprod*. 2nd Int Conf Proc 1991, Ed by Vourvopoulos G, WorldSci, Singapore.145-148.
55. 54. C.D., Mishra, HD, Pandey, B, Prasad and SR, Mediratta, "A method for rapid characterization of fly ash, residues effluents". in *Process Environ Consid Proc Int Symp* ed by Reddy RG, Imrie WP and Queneau PB, *Miner Met Mater Soc, Warrendale*,1992,149-155.
56. 55. B.R. Hart, MA Powell,WS Fyfe and B Ratanasthien , "Geochemistry and mineralogy of fly-ash from the Mac Mon. lignite deposit, Thailand". *Energy Sources*, 1995, **7**(1),23-40.
57. 56. C. Nerin, R. ZuFiaurre and J Cacho, "Critical study of several procedures for digestion of fly ash for analyses of As, Fe and Mn". *Analysis*,1992, **20**(10),597-600.
58. 57. JP Jojo, A Rawat, A Kumar and R Prasad, " Trace uranium analysis in Indian coal samples using the fission track technique". *Nucl Geophys*, 1993, **7**(3), 445-448.
59. 58. G.J. McCarthy, KD Swanson, LP Keller and WC Blatter, "Mineralogy of western fly ash".
60. *Cem Concr Res*, 1984, **14**(4), 471-478.
61. 59. LM Seaverson, JF McClelland, G Burnet, JW Anderegg and MK Iles, "Investigation of water and hydroxyl groups associated with coal fly ash by thermal desorption and Fourier transform infrared photacoustic spectroscopies". *Appl Spectrosc*, 1985, **39**(1),38-45.
62. 60. D. M. Disks and H.E. Allen, "Correlation of copper distribution in a fresh water sediment system to bioavailability". *Bull. Environ. Contam. Toxicol.*, 1983,**30**.37.
63. 61. R.H. Follett and W.L. Lindsay, "Changes in DTPA-Extractable Zinc, Iron, Manganese and copper in soils following fertilization". *Soil Sci. Soc. Am. Proc.*, 1971, 35,600.
64. 62. R.G. Gerrites, R. Vriesema, Dalinberg and H.P. Deroos, "Effect of sewage sludges on trace element mobility in soils". *J. Environ. Qual.*, 1982, 11, 359.
65. 63. W.L. Lindsay and W.A. Norvell, "Development of a DTPA soil test for zinc, iron manganese and copper". *soil, sci, soc, Am, J*, 1978, **42**, 421.
66. 64. J.J. Street, W.L. Lindsay and B.R. Sabey, "Solubility and plant uptake of Cd in soils amended with cadmium and sewage sludge." *J. Environ., Qual.*, 1977, 6(1), 72.
67. 65. B.L. Sawhney and C.R. Frink, "Heavy metals and their leachability in incinerator ash, Wat". *Air and Soil Poll*. 1991, 57, 289.
68. E.A. Jenne, "Control on Mn, Fe, Co, Ni, Cu and Zn concentration in soil and water. The significant role of hydrous Mn. Fe. Oxides". *Adv. Chem. Ser.*, 1968, 73,337.
69. D.K. Soni, D.S. Ramteke, A.L. Agrawal, "Aqua-status around thermal power plants with respect to physics, chemical characteristics". *Asian Environment*, 1990, **12**(1), 206.
70. J. Brown and N.J. Ray, "The Handling and disposal of coal ash in the CEGB in relation to the aqueous environment." *Wat. Sci. and Tech.*, 1983, 15,11.

71. D.M. Golden, "Water pollution arising from solid waste (coal, fly ash, slag) disposal and measures to prevent water pollution". *Water Science Tech.*, 1983, 15, 1.
72. J.H. Parker, P.M.I. Woodhead, I.W. Dwedall, and H.R. Carleton, "Ocean disposal and construction with stabilized coal waste blocks : What". *Sci. Tech.*, 1983, **15**, 83.
73. C.B. Sharma, "International conference on environmental impacts of coal utilization". IIT Bombay, 1991, 14-15 January, 265—276.
74. C.A. Sastry, "Pollution control in Thermal Power Plants". *Ecology*, 1988, 2(9), 19-29.
75. D.H. Klein, A.W. Andren, J.A. Carter, J.E. Emergy, C. Feidman, W. Fulerson, "Pathways of thirty seven trace elements through coal-fired power plant". *Environ. Sci. and Tech.*, 1975, **9**(10), 973.
76. R.L. Davison, F.S. David, Natersch, and J.R. Wallace, "Trace elements in fly ash: Dependence of concentration on particle size", 1974, 8(13), 1107.
77. M.H. Fulekar, D.S. Nail and J.M. Dave, "Heavy metal in Indian coals and corresponding fly ash and their relationship with particulate size". *Intern. J. Environmental Studies*, 1983(a) **21**, 179-182.
78. M.H. Fulekar and J.M. Dav, "Release and behaviour of Cr, Mn, Ni and Pb in a fly ash / soil / water / environment: Column experiment". *Intern. J. Environmental Studies*, 1991, **38**, 281-296.
79. F.A. Rohrman, "Analysing the effect of fly ash on water pollution", *power*, 1971, 115 (8), 76-77.
80. M.T. Phung, L.J. Lund, A.L. Page and G.R. Bradford, "Trace elements in fly ash and their release in water and treated soil". *J. Environ. Quality*, 1979, **8**, 171-175.
81. H. Matusienicz and D.Fs Natusch, "Ion chromatographic determination of soluble anions present in coal fly ash leachates". *Intern. J. Environ. Anal. Chem.*, 1980, **8**, 227-233.
82. M.H. Fulekar, D.S. Nail and J.H. Dave, 1983 b); Storage and release of fly ash constituents in an ash pond. *Asian Environment*, April-June 1983 (b).
83. M.H. Fulekar and J.M. Dave, "Environmental impact assessment of fly ash from coal-fired power plants". *Ecology*, 1990, **4** (8), 25-34.
84. S. Sharma, M.H. Fulekar and C.P. Jayalakshmi, "Fly ash dynamics in soil water system". *CRC Critical Reviews in Environ. Control*, 1989, **19**(3), 251-157.
85. D.S. Naik, M.H. Fulekar, and J.M. Dave, "Physico-chemical characteristics of ciling water in an ash pond". *Chem. Era.*, 1976, 19, 1115.
86. E.P.A. (U.S.), Report, "Elemental Flow in aquatic system surrounding coal-fired power plants" (July 1980) EPA 600, 3-80-076.
87. M.H. Fulekar and J.H. Dave, "Leaching of fly ash constituents along stream bed flow to Jamuna river, New Delhi". *Indian J. Env. Protection*, 1989, **9**(10), 773.
88. J.M. Wood, "Biological cycles for toxic elements in the environment". *Science*, 1974, 199, 1049-1052.
89. K.K. Bertine and E.D. Goldberg, "Fossil fuel combustion and the major sedimentary cycle". 1971, 173, 233- 235.
90. D.H. Klein and P. Russel, "Heavy metals: Fall out assoernid a power plant". *Environ. Sci. & Technol.*, 1973, 7, 357.
91. W. P. Ridley, L.J. Digikes and J.M. Wood, "Biomethylation of toxic elements in the environment". *Science*, 1977, 197, 329.
92. D. H. Klein and P. Russel, "Heavy metals: Fall out assoernid a power plant". *Environ. Sci. & Technol.*, 1973, 7, 357.
93. L. Friberg, "Cadmium in the environment", CRC Press, Cleveland, 1974.

94. Van Book, "R.I. Potential health and environmental effect of trace elements and radionuclides from increased coal utilization". *Environ. Health Prospect*, (1979), **33**, 227.
95. L.E. Wangen and F.B. Turner, "Trace elements in vegetation in downwind of coal-fired power plants". *Water, Air and Soil*, 1980, **13**, 99-108.
96. N.C. Bardy "Nature and properties of soil". 8th Edition Macmillan, New York, 1974, 639.
97. A.A. El-seevi, A.L. Page and I.R. Straughom, "Physical and chemical properties of fly ash from coal-fired plants high reference to environmental impacts", *Residue Rev.*, 1978, **7**, 83.
98. D.C. Adriano. A.L. Page, A.A. Elseevi, A.C. Chang and I.R. Straughom, "Utilisation and disposal of fly ash and other coal residues in terrestrial ecosystem: A review", *J. Environ. Qual.* 1980, **9**(3), 333.
99. M.H. Fulekar and J.M. Dave, "Heavy metals release from ash pond to soil water environment: A simulated technique", *Environment International*, 1982, **18**, 283-295.
100. A.C. Change, L.J. Lund, A.Z. Page and J.E. Warneke, "Physical Properties of fly ash amended soils". *J. Environ. Qual.* (b), 1977, **(3)**, 267.
101. M.F. Arthur, T.C. Zoick, D.A. Tolle and Van Varis, "Effect of fly ash on microbial CO₂ Evaluation from an agricultural soil, Water. Air". *Soil Pollut.*, 1984, **22**, 209.
102. J.P. Capp. "Power Plant fly ash utilisation for land reclamation in the eastern united states, in reclamation of drastically distributed lands", P. Ed. Soil Science Society of American Madison, WI, 1978, 339.
103. A.L. Page, A.A. Elseevi and I.R. Straugham, "Physical and chemical properties of fly ash from coal-fired plants high reference to environmental impacts". *Residue Rev.*, 1979, **7**, 83.
104. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Resource Conservation and Recovery. "Human and Ecological Risk Assessment of Coal Combustion Wastes." Draft EPA document, April 2010. 2-4.
105. U.S. Environmental Protection Agency. "Summary of Proven Cases with Damages to Groundwater and to Surface Water," Appendix, "Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals From Electric Utilities." Proposed rule. <http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccr-rule/fr-corrections.pdf>.
106. U.S. Environmental Protection Agency. "Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals from Electric Utilities." [EPA-HQ-RCRA-2009-0640; FRL-9149-4] Proposed rule. <http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccr-rule/fr-corrections.pdf>.
107. M.J. Kosnett, "Chronic Health Effects of Arsenic in Drinking Water: A Brief Summary." PowerPoint. University of Colorado Health Sciences Center. Undated.
108. Agency for Toxic Substances and Disease Registry (ATSDR), U.S. Department of Health & Human Services. ToxFAQs for Arsenic. <http://www.atsdr.cdc.gov/tfacts2.html>.
109. C.L. Chen, H.Y. Chiou, L.I. Hsu, Y.M. Hsueh, M.M. Wu, Y.H. Wang and C.J. Chen, "Arsenic in Drinking Water and Risk of Urinary Tract Cancer: A Follow-up Study from Northeastern Taiwan." *Cancer Epidemiol Biomarkers Prev*, 2010, **19**(1).
110. U.S. Environmental Protection Agency, Integrated Risk Information System, Lead and Compounds (inorganic) (CASRN 7439-92-1), available at

109. S.G. Gilbert and B.A. Weiss “Rationale for Lowering the Blood Lead Action Level from 10 to 2 $\mu\text{g/dL}$ ”. *Neurotoxic ology*, 2006, **27**(5), 693–701.
111. S.G. Gilbert, “Scientific Consensus Statement on Environmental Agents Associated with Neurodevelopmental Disorders.” Developed by the Collaborative on Health and the Environment’s Learning and Developmental Disabilities Initiative. February 20, 2008.
112. Barbara Gottlieb, Steven G. Gilbert and Lisa Gollin Evans, “Coal Ash: The toxic threat to our health and environment” A Report from Physicians for Social Responsibility and Earth justice. Washington, DC, September, 2010.

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