Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 12 [8] July 2023 : 413-419

Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD

REVIEW ARTICLE **OPEN ACCESS**

Fly Ash Disposal, Hazardous Effects and Eco-Safely Utilization in India: A Review

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ABSTRACT
Coal forms the backbone of India's energy system owing to its small cost and large profusion. Currently, 200 coal-based power plants contribute more than 75% of our total electricity generation. Due to the small caloric content (3000-3500 calories/Kg) and large ash quantity (30-45%) of Indian coal, the residual lightweight by-product fly ash is generated in copious volumes by charcoal combustion in power stations. This fly ash can cause severe geo-environmental degradation and health issues, if not administered scientifically. Also, its disposal poses a great threat due to associated socio-economic problems. The utility of fly ash has risen from 13.54 million tonnes (15.70%) in 2000-01 to the highest value of 259.86 million tonnes (95.95%) in 2021-22 due to the substantial efforts carried out by the prestigious fly ash project of the Indian government.
Keywords: *Charcoal, Eco-safely, Fly ash, Geo-environmental degradation, Thermal power stations.*

Received 23.04.2023 Revised 12.05.2023 Accepted 21.07.2023

INTRODUCTION

Electricity performs a pivotal function in the modern techno-savvy world. In an emerging nation such as India, electricity is the lifeline and source of fuel for almost all-important domains like agriculture, industries, education, health, transport communication etc. It largely affects the economic development of our country. Coal forms the backbone of the Indian energy system due to its abundance and cheap cost. It contributes 58% of the country's primary energy supply and out of the entire electricity produced,75% share is from thermic power stations [1]. According to the Geological Survey of India, the all-India coal production was 778.19 million tonnes in the year 2021-22. India will largely hang on coal for the production of energy till the year 2031-32 and in forthcoming times, although the country is continuously exploring other functional alternative renewable energy resources [2].

Kinds of Fly Ash and Their Chemical Constitution

Fly ash is chemically a non-organic mineral consisting of ferrous aluminium-silicate matter. It is a heterogeneous combination of various compounds like silicon dioxide (or SiO_2), ferric oxide (or Fe_2O_3), alumina oxide (or Al_2O_3) and quick lime (or CaO) [3]. It contains all those heavy elements in minute quantities that are found in common soil [4]. An insoluble cement-like solid substance is formed at room temperature via a reaction taking place between pozzolanic fly ash, calcium oxide (CaO) and water [5]. Fly ash possesses the following heavy elements in trace quantity- lead (Pb), uranium (U), cobalt (Co), nickel (Ni), zinc (Zn), chromium (Cr), thorium (Th), Copper (Cu), boron (B) and mercury (Hg) etc. [6]. The x-ray photographic studies of fly ash confirm that 70-90% part of it consists of heterogeneous glass-like spherical particles while the rest of the part contains diverse crystalline phases like quartz glass, mullite mineral and red iron oxide (or hematite) and magnetic iron ore (or magnetite) like iron oxides and unburnt carbon [7]. American Standards of Testing Materials (ASTM) divides fly ash into two main types (type-C and type-F) based on charcoal source and chemical elements constitution [8]. Table 1 shows the difference between them [9].

Table 1: Kind of fly ash and their chemical components

Properties	Type-C Fly Ash	Type-F Fly Ash
SiO_2 + Fe_2O_3 +Al_2O_3	50 to 70 %	>70%
SO_3	3	1
MgO (magnesia)	5	2
CaO (lime)	Greater than 20% lime	Less than 7% lime
Origin of Fly ash	From the firing of lignite and sub-bituminous charcoal	From the firing of bituminous and anthracite charcoal
Loss of ignition	Lower	Higher
Features displayed	Self-setting and Pozzolanic feature	Pozzolanic feature

Physical Features of Fly Ash

Fly ash is mainly constituted of minute glass-like void particles known as Cenospheres. These lightweight particles of 0.01-100 mm in size have a high surface area. The average diameter of fly ash particles is less than 10-micron meters and their bulk density is 2.1-2.6 gram per centimetre cube [10]. The main core (60%) of fly ash is constituted by silt-like particles (0.02-0.002 mm), 25% part has sand-like particles (2-0.02 mm) and 10% part has clay-like particles (less than 0.002 mm) [11]. The moisture-grasping ability of fly ash varies between 35-40% and porosity is 50-60% [12]. The electrical conductance of fly ash ranges between 42-450 microns Siemens per centimetre (μS/cm) [13]. The potential of hydrogen (i.e. pH scale) of fly ash extends in between 4.5 and 12 and it is determined by the sulphur quantity of the parent coal which itself is governed by the quality of the coal used for firing. The fly ash obtained from anthracite coal is acidic due to high sulphur substance while fly ash obtained from lignite coal is alkaline because of little sulphur and high calcium matter [14]. Indian charcoal has a huge ash quantity (30-45%) and small calory content (3000-3500 Calory/Kg) owing to minute sulphur content [15].

Disposal of Fly Ash

An enormous load of fly ash is produced annually as a waste side-product in charcoal-based thermic power stations. The power station ash is a combination of coarse residual ash (20%) and fine fly ash (80%) [16]. The electrostatic precipitators or mechanical instruments called 'cyclones' are used to collect fly ash that is taken away by flue gases in the boiler [17]. Conventionally, the mixture of fly ash and residual ash is collected either in dry state (as mound ash) or in wet or slurry form (as pond ash) in special ponds known as ash ponds or ash dykes (3-4). In India, almost 80% of fly ash is discarded in a wet/sludge (or slurry) state. Generally, water and fly ash in a 9:1 ratio is used for this purpose. Apart from this, water is utilized in boilers, air cooling, air conditioning, and auxiliary systems needed for water cooling. Hence, thermic power plants are constructed near rivers for expedient water supply [18]. A large precious land resource is required for dumping copious amounts of fly ash. A general rule of thumb is that one acre of land resource is essential per megawatt of power production [4]

Harmful Impacts of Fly Ash on Eco-system

Fly ash ponds lead to desertification in ecosystems by altering their geo-morphology and water drainage system. The fatal metals of fly ash have the capability of leaching into soil and polluting rivers, underground water resources and deep soil by mixing with surface run-offs [19]. During monsoons, the breaching of embankments of old and unlined ash dykes generally leads to the discharge of vast quantities of fly ashes in nearby water reservoirs and land used for agriculture and human habitats. Similarly, in summer, the dust storms carry large ash clouds into the environment and become a major source of air pollution. In a survey carried out by the national green tribunal in Ennore, north Chennai, a high concentration of toxic heavy metals was detected in rivers and water resources, polluted by fly ash. Also, the aquatic animals (i.e., prawns, crabs, fishes and oysters) present in them, exhibited a high concentration of lethal metals like copper, lead, selenium and cadmium due to bio-accumulation and bio-magnification. The selenium metal is the main cause of organ deformities in larvae of fishes. It gets concentrated in the yolk of growing embryos and leads to the reproductive failure and extinction of several species [20].

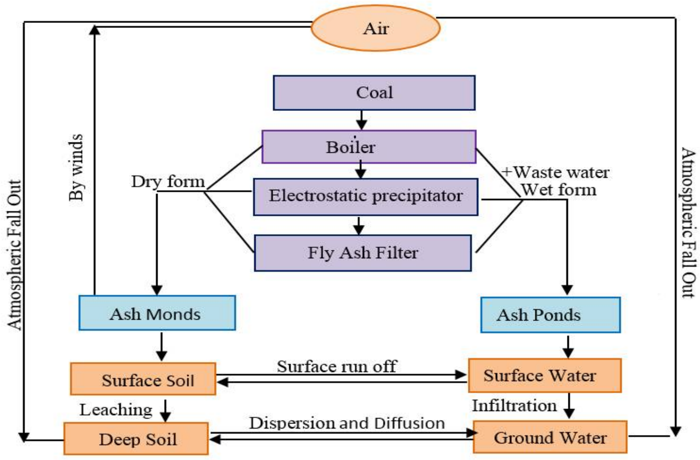

Figure 1: Fly ash production, disposal and related environmental pollution

In India, 10% part of the total fly ash generated is discharged as atmospheric particulate substance in the surrounding air by chimneys while 85 to 90% part of fly ash is discarded in fly ash ponds [21]. The tiny fly ash particles of size ranging between 1-10 microns can easily reach inside the body via inhalation by nose and mouth. Fly ash particles of less than 1 micron get disposed of on the alveolar walls of lungs and the lethal metals enter into blood plasma via cell membranes. These metals can instigate asthma, bronchitis and lung cancer over a long span [22]. Table 3 shows fatal metals existent in fly ash, their limiting value in air and water and their deleterious effects on human health [18, 21-22].

Table 2: Fatal metals present in fly ash, their limiting value in air and water and their deleterious impacts on human health.

Fatal Metals of Fly Ash	Limiting value-air (mg/m3)	Limiting value-water (mg/L)	Deleterious impacts on human health.
Copper (Cu)	0.2	< 1	Wilson disease, liver disease
Lead (Pb)	0.15 (in 8 hrs.)	0.05	Neurotoxic and carcinogenic, causes lead poisoning (metallic taste, nausea, muscle cramps, high blood pressure, and damage to the brain and kidney.
Nickel (Ni)	0.007 (carbonyl) 1.0 (metal)	< 0.005	Scarring of lung tissues (i.e., lung cancer), acute bronchitis, and reproductive failure in humans.
Chromium (Cr)	between 0.1-0.5	< 0.005	Skin cancer, chest congestion, wheezing and coughing leading to asthmatic attack.
Cadmium (Cd)	between 0.1-0.05	0.01	Carcinogenic, bone-marrow and renal damage, high blood pressure
Manganese (Mn)	between 0.3-10	< 0.005	Neurotoxic (i.e., irreversible brain damage) damage to the liver and kidney, reduces male fertility, Parkinson's' disease (loss of facial expression, muscle coordination, effects on speech, balance, mood and personality).
Mercury (Hg)	0.005	0.005	Permanent damage to kidneys and developing foetus, Minamata disease (incoordination, seizures, blindness, vision-hearing and memory problems)

The coal usage of approximately 1800 million tonnes along with the production of 600 million tonnes of fly ash has been estimated by the Indian Ministry of Power per year till 2031-32 [23]. Fly ash can produce serious geo-environmental degradation and detrimental health issues in the absence of proper scientific disposal methods. It also poses a great menace to its disposal due to the associated socio-economic

problems. Hence, eco-safely management and sound disposal of this gigantic amount of fly ash is a great task in modern scenarios [24].
The "Fly Ash Scheme" of the Indian administration, launched in the year 1994, is a combined functional task of the Ministry related to Environment, Forest and Climate Change (MoEF & CC), the Ministry of Electricity and the Science and Technology Ministry being the coordinating agency [25]. Its prime target is to promote nature-friendly management and productive utility of fly ash and to encourage research and advancement of fly ash-added products. The fly ash is now regarded as an "expedient resource material" instead of an "industry-based waste" due to the commendable efforts carried out by the fly ash project [26]. Table 3 represents the number of thermic power stations, charcoal consumption (MT), percentage ash quantity, and fly ash production-utilization (MT) in the last five years in comparison to the year 2000-01 [1,25,27-29].

Table 3: The number of thermic power plants (TPP'S), coal use (MT), ash content (%), and fly ash production (MT) in the year 2000-01 and during years 2017-22.

Year	2000-01	2017-18	2018-19	2019-20	2020-21	2021-22
Number of TPP's	-	167	195	194	202	200
Use of Coal (MT)	-	624.88	667.43	406.91	686.34	759.02
Ash Content (%)	-	31.44	32.52	31.73	33.88	35.68
Ash Production (MT)	86.29	196.44	217.04	129.09	232.56	270.82
Fly Ash Use (MT)	13.54	137.87	168.40	100.94	214.91	259.86
Fly Ash Use (%)	15.70	67.13	77.59	78.19	92.41	95.95

Figure 2 represents the percentage usage of fly ash in varying zones in India throughout the year 2021-22. The utmost usage of fly ash has been achieved in cement production (26.23%) and minimum in the agricultural sector (0.06%).

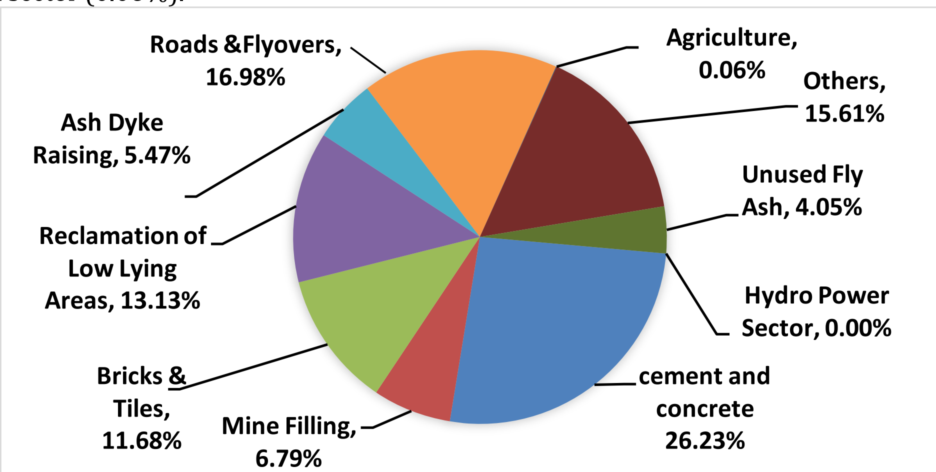

Figure 2: Percentage utilisation of fly ash in various sectors in India during the year 2021-22.

(1) Figure 3 shows that fly ash production-utilisation has increased progressively between the year 2011-22 in comparison to the year 1998-99. However, the production of fly ash was less in the year 2016-17 (than in the year 2015-16) due to less consumption of coal.
(2) The production of fly ash has increased 3.43 times in the year 2021-22 (270.82MT) in comparison to the year 1998-99 (78.99 MT).
(3) The utilisation of fly ash was 9.22 MT in the year 1998-99 and has increased to a maximum level of 259.86 MT (95.95%) in the year 2021-22, till now.

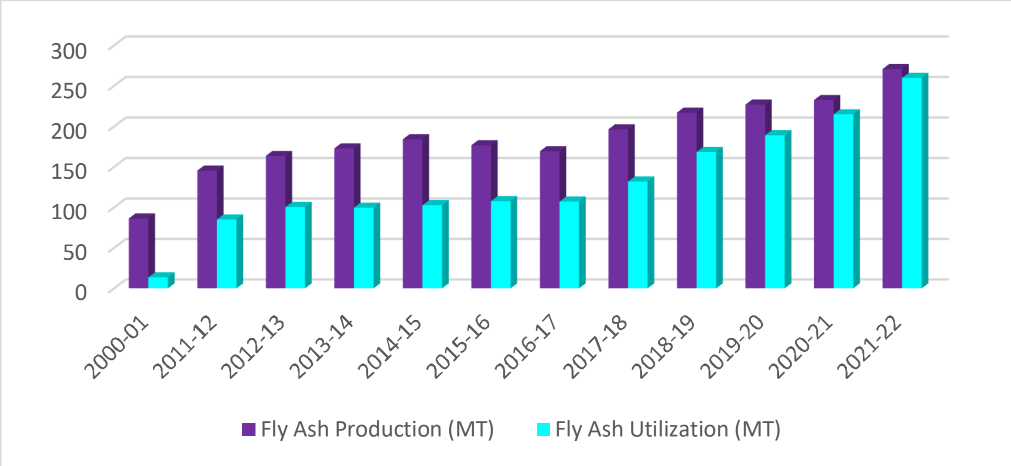

Figure 3: Fly ash production-utilisation during the years 2011-22 in comparison to the year 2000-01.

Eco-Friendly Utilisation of Fly Ash in India: The diverse usage of fly ash are as follows -

(1) **Cement Industry:** India, being a developing country, has a vast potential for the application of fly ash in the 'construction field.' Studies indicate that the synthesis of 1 ton of general-purpose cement or Portland cement, the most frequently used cement worldwide, liberates 1–tonn of carbonic acid gas in the surroundings that chiefly accounts for the global rise in temperature [30]. Substitution of cement partially by fly ash not only lowers the greenhouse gas release but conserves useful natural resource materials like coal, limestone etc. as precious land resources. On the contrary, this replacement extends the mechanical benefits of cement/concrete and provides an effective alternate way for the safe discarding and gainful utility of fly ash [23,31].

Pozzolanic Portland Cement (PPC): The manufacturing of Portland Pozzolana Cement requires the mixing of 15-30% type-F fly ash in normal Portland cement. The use of 'Roller Compacted Concrete' in huge dams like the Ghatghar dam project of Maharashtra, involves the substitution of fly ash up to 70% that confers strength by reducing thermal cracking [32]. The utilization level of fly ash was only 2.45 million tonnes in the year 1998-99 but has gained up to 71.05 million tonnes (26.23%) in the year 2021-22 [1].

(2) Fly Ash-Added Bricks, Tiles and Concrete Blocks: The utilization of fly ash-added construction materials not only saves upper fertile soil but is comparatively cost-effective and more durable than conventional building materials [33]. The operation of fly ash has risen from 0.70 million tonnes in the year 1998-99 to 31.62 million tonnes (11.68%) in the year 2021-22 [1].

(3) Agriculture: As the Indian economy is based on agriculture, forestry, horticulture and the agriculture sector have an unlimited potential for incorporation of huge amounts of fly ash. The consumption of fly ash has decreased from 0.13 million tonnes in the year 1998-99 to 0.15 million tonnes (0.06%) during 2021-22 [1]. The application of fly ash in the agriculture sector offers the following advantages-

(i) Fly ash significantly enhances moisture retaining capacity, permeability and vigour of soil. Owing to its alkaline nature (pH 4.5-12), fly ash is capable of neutralizing acidic soil and thus acts as an efficient soil modifier [7].

(ii) Fly ash is a vital reservoir of all trace and major nutrient elements fundamental for the healthy growth of plants except for nitrogen and carbon. Fly ash accelerates the growth of plants by enhancing the absorption of nutrient elements [34].

(iii) Studies indicate that the addition of fly ash improves the productivity of cereal grain, pulses, oil-containing seeds, cotton fibre and saccharum (or sugarcane) in the range of 10-15% and veggies by 20 to 25% [4,23].

(4) Filling of Abandoned Mines: The dual advantage of conserving priceless fertile soil and river sand is achieved by applying fly ash in the filling of abandoned mines. In comparison to the year 1998-99, the utility of fly ash in this domain has substantially boosted from 0.65 million tonnes to 18.38 million tonnes (6.79%) in 2021-22 [1].

(5) Retrieval of low-placing areas: The problem of water-clogging in low-placing areas could be handled efficiently by the incorporation of fly ash along with the conservation of sand and fertile soil. The consumption of fly ash in this field was 35.57 million tonnes (13.13%) in 2020-21 contrary to only 4.17 million tonnes in 1998-99 [1].

(6) Creation of flyovers, pavements, roads and increasing height of ash ponds: The distribution of particle size, permeability and compressibility of fly ash particles are some of the important factors for the above applications. Fly ash exhibits better compaction properties than soil owing to the large value of the uniformity coefficient of its clay-like particles [36-37]. The usage of fly ash has expanded from 1.055 million tonnes during the year 1998-99 to 60.81 million tonnes (22.45%) in the year 2021-22 [1].

CONCLUSION

Due to the concrete efforts of the fly ash project, its policies related to disposal-utilisation of fly ash and scientific research, the highest level of fly ash utilization (95.95%) till now, has been achieved in the year 2021-22. Being a developing country, India's economy depends on agriculture. Hence, construction and agriculture are two prime sectors that offer large applications of fly ash. Also, it is the need of the hour to explore other new domains like metal recovery, pollution control, stabilization of waste materials etc. that have a huge capability to incorporate gigantic amounts of fly ash. However, it is essential to consider the economic viability and inherent deleterious health issues and environmental impacts of fly ash, so that all the potential of this treasurable resource matter could be fully explored.

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CITATION OF THIS ARTICLE

Rekha S, Rajendra S, Sudha S. S, Preeti A Fly Ash Disposal, Hazardous Effects and Eco-Safely Utilization in India: A Review.Bull. Env. Pharmacol. Life Sci., Vol 12 [8] July 2023: 413-419