Fly ash characterization, utilization and Government initiatives in India – A review

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Current annual production of fly ash, a by-product from coal based thermal power plants (TPPs), is 112 million tonnes (MT). Some of the problems associated with fly ash are large area of land required for disposal and toxicity associated with heavy metal leached to groundwater. This review presents different ways of using fly ash and policies of Govt of India regarding utilization and disposal of fly ash. Environmental and occupational health hazards associated with fly ash are also discussed.

Keywords: Environment, Fly ash, Occupational health, Thermal power plants

Introduction

In India, studies have been carried out towards management of fly ash (FA) disposal and utilization¹². Of total power generated in India, about 70% is produced by thermal power plants (TPPs). With a 70 billion tonnes coal reserve, majority of TPPs (84%) are run on coal¹ and rest on gas (13%) and oil (3%). About 260 million tonnes (MT) of coal (65% of annual coal produced in India) is being used by TPPs⁴. Presently, over 112 MT of fly ash is being generated by TPPs as a byproduct of coal combustion. FA quality depends on coal, coal particle fineness, percentage of ash in coal, combustion technique used, air/fuel ratio, burners used, and type of boiler.

Fly ash – Hazard to Environment and Life

FA contains trace amounts of toxic metals (U, Th, Cr, Pb, Hg, Cd etc.), which may have negative effect on human health and on plants. Several studies have been carried out to assess hazards caused by FA on environment and plants⁵-⁷. SO₄²⁻ and NO₃⁻ released from TPP cause acid rain, which corrodes structural surfaces and may affect agriculture by causing yellowing of green leaves. Thermal pollution due to disposal in surface water sources disrupts aquatic life, whereas toxic metals leached contaminate underground water resources. Light and continuous prolonged inhalation causes pneumonitis, allergy, asthma, lung fibrosis, bronchitis, cancer, and silicosis⁸-⁹.

Limited studies have been done on potential of silicosis and lung cancer associated with crystalline silica component of FA. Hicks & Yager⁰ measured amount of airborne respirable crystalline silica (quartz) in the breathing zone of workers exposed to coal fly ash (CFA) from six coal-fired plants using bituminous, sub-bituminous and lignite coal. Air samples (60%), obtained during maintenance activities of bituminous and sub-bituminous fired power plants, exceeded threshold limit value (TLV), whereas samples obtained during normal production activities of bituminous (54%) and sub-bituminous plants (65%) also exceeded TLVs. Mean crystalline silica content in dust samples was found in bituminous/sub-bituminous plant (7.5%) and in lignite plant (1.7%). Rapparort et al¹¹ found that construction workers were overexposed to dust and silica exposures to the occupational exposure limits. Cases of asthma¹² in a worker at a power station caused by inhalation of pulverised fuel ash and acute lung disease¹³ after intensive exposure to FA in a 48-year-old man with no previous history of pulmonary disease are reported.

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Bird et al\textsuperscript{14} studied occupational exposures in five coal fueled power plant in terms of coal dust, silica, arsenic (As), asbestos, noise, and heat stress. Silica (quartz) ranged from \( \leq 0.6 \) to 4.4\% in coal samples. Area samples (12 out of 61) were higher in asbestos than limit of detection (0.003 f/cc). Noise samples (55 out of 302) were higher than or equal to permissible level of 85 decibels. In another study, Yager et al\textsuperscript{15} studied occupational exposure to inorganic As in FA and urinary excretion of As metabolites in 40 healthy workers during routine maintenance outage in a coal fired power plant in Slovakia. The study showed that mean airborne As was 48.3 \( \mu \)g/m\(^3\) (0.2-375), whereas predicted urinary As (at 10 \( \mu \)g/m\(^3\)) was 13 \( \mu \)g/m\(^3\). Arithmetic means for air As was 138.9 (boiler cleaners), 67.7 (boilermakers) and 5.7 \( \mu \)g/m\(^3\) (technicians). The study indicated bioavailability of As from airborne CFA.

Characteristics of Fly Ash

Indian coal belongs to sub-bituminous, bituminous or lignite quality. It has following values:\textsuperscript{3, 38} moisture, 1.9-8.3; C, 39.3-60.2; H, 2.8-4.2; S, 0.3-0.5; N, 0.9-1.9; and O, 4.9-9.3\%; calorific value, 3850-4250 kcal/kg; and FA fraction, 78.2-90.5\%/w. American coal is superior to Indian coal and has following values: moisture, 1.1-2.8; C, 64.2-72.4; H, 5.0-5.2; S, 1.2-2.4; N, 1.3-1.6; and O, 5.0-12.9\%; calorific value, 6378-7728 kcal/kg; and FA fraction, 51-60\%/w. Australian coal falls between Indian and American coal.

Physical Properties

FA particles\textsuperscript{16} are usually very fine, light weight (density 1.97-2.89 g/cc), and spherical (specific surface area, 4000-10,000 \( \text{cm}^2/\text{g} \); diam, 1-150 \( \mu \)) refractory and have pozzolanic ability\textsuperscript{17}. FA is grey to blackish grey and is dependent on coal type and combustion process. FA has dielectric property\textsuperscript{18} (dielectric constant, 10\(^5\)) and can be used in electronic applications.

Chemical Properties

Chemical composition\textsuperscript{19-26} of FA is as follows: SiO\(_2\), 59.38; Al\(_2\)O\(_3\), 23.59; Fe\(_2\)O\(_3\), 6.11; CaO, 1.94; MgO, 0.97; SO\(_3\), 0.76; alkalies, 1.41; and unburnt S & moisture, 3.74\%. According to ASTM C618\textsuperscript{27}, FA is classified into two classes (C and F) based on the amount of lime present. Class C is lignite and sub-bituminous coal (>10% CaO), whereas class F is bituminous or anthracite coal (<10% CaO). Oxides of silicon, aluminum, calcium, and iron in FA are responsible for pozzolanic activity, which decreases by loss of ignition\textsuperscript{28}. Indian FA also contains toxic and heavy metals. Though heavy metals are found in detectable quantity, their concentration is less when compared to other countries\textsuperscript{29}. FA contains following toxic metals\textsuperscript{8, 30}: Hg, 1; Cd, Ga, Sb, Se, Ti and V, 1-10; As, Cr, La, Mo, Ni, Pb, Th, U and Zn, 10-100; and B, Ba, Cu, Mn and Sr, 100-1000 mg/kg. Studies have been done on their leaching behaviour\textsuperscript{31} as well as their accumulation and effect on growth of vegetation\textsuperscript{32-33}. Heavy metals (As, Mn, Mo and Fe) show leaching with concentration above permissible limit. Indian FA contains radionuclides\textsuperscript{34, 35} (Table 1). Release of radionuclide from radon (annual average conc. in an Indian TPP, 75 \( \pm 32.5 \) Bq m\(^{-3}\)), is within permissible limit\textsuperscript{36}. Average annual radon exposure limit\textsuperscript{37} set by International commission on radiological protection (ICRP), 1993 is 200-600 Bq m\(^{-3}\).

Fly Ash Utilization

High disposal cost (Rs 50-100/MT) and large area of land required for disposal of ash demands utilization of FA to the maximum extent.

(i) Pulverized Fly Ash (PFA) in Concrete

Ultra fine particles of FA are most preferred option for improving concrete strength and durability. Use of

<table>
<thead>
<tr>
<th>TPPs</th>
<th>Average concentration, Bq/kg</th>
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<tbody>
<tr>
<td></td>
<td>(^{226}\text{Ra})</td>
</tr>
<tr>
<td>Allahabad (UP)</td>
<td>94.4</td>
</tr>
<tr>
<td>Angul (Orissa)</td>
<td>82.2</td>
</tr>
<tr>
<td>Badarpur (Delhi)</td>
<td>71.3</td>
</tr>
<tr>
<td>Choudwar (Orissa)</td>
<td>100.1</td>
</tr>
<tr>
<td>Dhamanjodi (Orissa)</td>
<td>82.5</td>
</tr>
<tr>
<td>Bakreswar (WB)</td>
<td>83.7</td>
</tr>
<tr>
<td>Farakka (WB)</td>
<td>88.9</td>
</tr>
<tr>
<td>Kolaghat (WB)</td>
<td>94.6</td>
</tr>
<tr>
<td>Neyveli (TN)</td>
<td>44.9</td>
</tr>
<tr>
<td>Raichur (Karnataka)</td>
<td>99.1</td>
</tr>
<tr>
<td>Rihandnagar (UP)</td>
<td>80.8</td>
</tr>
<tr>
<td>Talcher (Orissa)</td>
<td>83.8</td>
</tr>
</tbody>
</table>

Table 1 – Average concentration of natural radionuclide in fly ash from thermal power plants in India\textsuperscript{31}
FA leads to impermeable concrete, reduces heat of hydration in mass concrete and prevents serious problems due to alkali aggregate reaction. FA (60-70%) ash can be used in roller compacted concrete, whereas 20-40% can be used in ordinary, cellular lightweight and high performance concrete. Replacement of concrete with FA (up to 40%) in the production of cement can save partial (11%) manufacturing cost. Although strength of concrete starts reducing as the amount of FA increases, but improvement in strength is seen with age.

(ii) PFA use in Cement Industries

Portland Pozzolana Cement (PPC), superior to ordinary portland cement (OPC), has low heat of hydration. FA (15-20%, 25 MT/y) can be utilized in the manufacture of PPC, at present annual production of 110 MT of OPC. This will cut CO₂ production (25 MT) at the rate of one tonne CO₂ per tonne production of cement.

(iii) Fly Ash Bricks

FA (15 MT/y) can be used in making bricks and can save on partially (10-15%) of total demand (100 billion bricks/y). Even though, PFA brick at first instance may appear to be costlier than conventional product, ultimate financial benefits can be evaluated in terms of its proposed to use another 67 lakh m³ of OPC. This will cut CO₂ production (25 MT) at the rate of one tonne CO₂ per tonne production of cement.

(iv) Fly Ash in Road Construction

FA may be used in road construction for: (i) Stabilizing and constructing sub-base or base; (ii) Upper layers of pavements; and (iii) Filling purposes. Concrete with FA (10-20% by wt) is cost effective and improves performance of rigid pavement. Soil mixed with FA or with FA and lime increases California Bearing Ratio (CBR), which increased (84.6%) on addition of only FA to soil. Addition of FA has not shown any adverse effects on the ground water quality in the vicinity of experimental plots. National Highway Authority of India (NHAI) is currently using 60 lakh m³ of FA and proposed to use another 67 lakh m³ in future projects.

(v) PFA Use in Agriculture

Even if few (10%) cultivators use FA (10 MT/ha), agricultural sector will require 170 MT FA each year, which will fall short of the total FA production (112 MT/y). However, this shortfall can be met from accumulated stock of 1000 MT of ash ponds near TPPs. While proper implementation of legislation is required to promote utilization of FA for making bricks and various building materials, no compulsion can be made for use of PFA in agriculture.

FA has been found capable of reducing infection in the crops. FA reduces bulk density, improves water holding capacity (WHC) and soil aeration, and provides macronutrients (K, P, and Ca). FA (8%) increases electrical conductivity (160%) and organic carbon (102.5%), and may increase available micronutrients (Zn, 20.67; Cu, 37.59; Fe, 11.0; and Mn, 74.88%). FA in conjunction with gypsum reclaims saline alkali soils, resulting in saving, of gypsum (50-75%). Low dose (2-4%) of FA has shown an increase in the average plant height, root length, yield as well as biomass of wheat (Triticum vulgare), mustard (Brassica juncea), pea (Pisum sativum) and gram (Cicer arietinum). An increase of fresh weight (114.91%) is seen in Cucumis sativus when soil is treated with FA (25%). Several more studies on effect of crops grown in variety of soil have shown insignificant increase in trace metals, increase in nutrient component of soil and crop yield with use of FA in lower concentration but unfavorable conditions for growth at higher concentration. Study has also indicated that FA can be more beneficial when used in combination with organic additions.

(vi) Water and Wastewater Treatment

Studies have been carried out for using FA to treat domestic wastewater and toxic metals. FA as an adsorbent for removal of industrial waste like dyes has also been extensively studied. FA is capable of removing As (V) (98-100%) and treated water has neutral pH (7.0-8.0). At pH 6.5, FA can remove fluoride (up to 94%). At high temperature and low pH, FA in combination with Kaolin can be successfully used to remove Cr(VI). Impregnated FA with 0.1 M Al₃(NO₃)₃ or FeCl₃ is capable of removing (90-95%) of Ni(II) and Zn(II). Impregnated FA with 0.1 M Al₃(NO₃)₃ is also capable of removing Cr(VI) (up to 90%). COD can also be used to reduce COD in domestic water.

(vii) Ash Ponds and Dams

Technologies have been developed for construction of ash dykes using FA in place of soil. Ash ponds can be...
densified using FA to make them safe under seismic conditions.

**Global Scenario**

During 2005 (Table 2), Italy, Denmark and Netherland, which have annual FA generation of 2 MT, show 100% utilization, whereas USA, Germany, which produce more FA (10-75 MT/y), uses around 50-85% FA only. Major applications are in cement, concrete, mine fill and bricks etc. FA generation in India (112MT/y) and China (100 MT/y) is utilized only up to 38 and 45% respectively. In Poland and Germany, bulk quantity of FA is used for mine filling, cement and concrete. FA (80%) in developed countries is used for brick manufacture, road construction, landfill, dam construction, agriculture etc.

**Indian Scenario**

Utilization at 3% from of the total 40 MT production of FA in 1994 has increased to 38% (42 MT) of 112 MT produced during 2004-05. Earlier utilization was limited predominantly for ash bund construction, landfill and partly for production of bricks and cement. Presently, cement manufacturing and road construction are major consumers of FA as follows: cement manufacture/substitution, 49; road and embankments, 21; low lying area filling, 17; dyke raising, 4; brick manufacturing, 2; mine filling, 2; agriculture, 1; and others, 3%.

**Government of India’s Initiatives – Policies and Programmes**

**Ministry of Environment and Forests (MoEF)**

MoEF has issued a notification (14 Sept 1999) on promotion of FA with following salient features: i) No person shall within a radius of 50 km from coal or lignite based TPPs manufacture clay bricks or tiles or blocks for use in construction activities without mixing at least 25% of ash (FA, bottom ash or pond ash) with soil on weight-to-weight basis; ii) Every coal or lignite based TPPs shall make available FA, for at least 10 years from the date of publication of this notification, without any payment or any other consideration for manufacturing FA-based products (cement, concrete blocks, bricks, panels or any other material) or for construction of roads, embankment, dams, dykes or any other construction activities; iii) Central and State government agencies (SEBs, NTPC and TPPs) shall facilitate land, electricity and water for manufacturing activities and provide access to ash lifting area for promoting and setting up ash based production units in the proximity of the area where ash is generated by TPPs; iv) CPWD, SPWD, development authorities, housing boards, NHAI and other construction agencies including those in private sector shall also prescribe the use of FA and FA-based products in their respective schedule of specifications and construction applications including appropriate standards and codes of practice within a period of 4 months from publication of this notification.

**Fly Ash Utilization Program (FAUP)**

Technology Information Forecasting and Assessment Council (TIFAC) under Department of Science & Technology (DST), Govt of India, New Delhi, has started Fly Ash Utilization Programme (FAUP) in 1994, with main objectives to make FA a useful by-product, to reduce environmental pollution, to reduce land required for FA disposal and to economise construction (utilization of coal ash for land and mine fill and in agriculture, perspective on bulk use of FA). FA generation is expected to increase to 170 MT by the end of XI five-year plan.

**State Governments**

**Orissa Government**

It has been decided that: i) Dry/wet FA to be supplied by power station/unit generating FA free of cost to entrepreneurs for 20 years to start with from the day the unit goes into FA based production; ii) Land/water required to set up FA based plant to be provided free by concerned power plant; and iii) For 5 years, exempted from electricity payment duty and power free of cost provided by the power plant.

**Rajasthan Government**

Entire sales tax and octroi exemption for 10 years from the date of commercial production for setting up

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**Table 2 – Fly ash generation and utilization in different countries**

<table>
<thead>
<tr>
<th>S No</th>
<th>Country</th>
<th>Annual ash production, MT</th>
<th>Ash utilization %</th>
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<tbody>
<tr>
<td>1</td>
<td>India</td>
<td>112</td>
<td>38</td>
</tr>
<tr>
<td>2</td>
<td>China</td>
<td>100</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>USA</td>
<td>75</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>Germany</td>
<td>40</td>
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<td>7</td>
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<td>6</td>
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<td>8</td>
<td>France</td>
<td>3</td>
<td>85</td>
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<td>9</td>
<td>Denmark</td>
<td>2</td>
<td>100</td>
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<td>10</td>
<td>Italy</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>Netherlands</td>
<td>2</td>
<td>100</td>
</tr>
</tbody>
</table>
manufacturing facilities for bricks, building materials and other FA based products.

**Maharashtra Government**

Maharashtra government has made it mandatory for any agency involved in constructing buildings within 50-100 km from coal or lignite based TPP to use FA bricks or blocks and tiles, clay FA bricks, cement fly ash bricks or blocks. During 2005-06, FA (25.16%) produced from nine Maharashtra based TPPs (Nashik, Parli, Koradi, Paras, Chandrapur, Khaperkheda, Bhusawal, Dahanu, and TATA) have been used in cement industry, brick kiln manufacturing, landfills, ash based products, agriculture and other activities.

**Future Technologies**

FA can be used as a resource material for alumina, magnetite, carbon, cenospheres, mineral fillers, enhanced pozzolana and other minor and trace items. FA, as a raw material can be used in manufacture of high wear resistant ceramic tile, mineral wool, glazed floor and wall tiles, ash alloys, synthetic wood, decorative glass and fire abatement applications. It can be used as absorbent for toxic organic, in foam insulation products, ceramic fiber, distemper, continuous casting mould powder, FA based Zeolite-A, FA based Zeolite-Y and ultra light hollow sphere for arid zone cultivation. FaL-G bricks manufacturing technology, developed by Institute for Solid Waste Research & Ecological Balance (INSWAREB), consists of bricks produced from a combination of FA, lime and gypsum. FaL-G bricks, about 4 billion produced annually, are light, durable and suitable replacement for conventional concrete bricks for building construction.

**Conclusions**

FA has become an important raw material for various industrial and construction applications. FA is widely used in construction of bricks, cement, asbestos-cement products and roads/embankments. FA is being studied for improvement of agricultural crops, wastelands, and zeolites. FA has found application in domestic and wastewater treatment and purification, and paint and enamel manufacturing. In future, large-scale application of FA may be possible for recovery of heavy metals, reclamation of wasteland, and floriculture.

**References**


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