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A review on sustainable approach for management of fly ash in different sectors – Indian scenario

Fly ash is generated during the burning of pulverized coal in coal-fired power stations. In India, large quantity of fly ash is being produced, as most of our energy demand is met through coal based thermal power stations. Some of the problems associated with fly ash are huge amount of land required for disposal and toxicity associated with heavy metal leached to groundwater. Materials having potential for gainful utilization remain in the category of waste till its potential is realized and is put to good use. This paper presents different ways of using fly ash in various sectors.

Keywords: Fly ash, coal-fired power stations, utilization.

Introduction

Fly ash has been classified as a Green List waste under the Organization for Economic Cooperation and Development (OECD). It is not received as a waste under the Basel Convention [1]. India is the third biggest producer of coal in the world [2]. Wide scale coal firing for power generation began in the 1920s [3]. Dependency on coal-fired power plants for electrical generation in many countries in present time ongoing environmental challenges [4]. The amount of fly ash released by factories and thermal power plant has been increased throughout the world. So the disposal of fly ash becomes a grave environmental and economic problem [5, 6]. Fly ash consist of particles moving up from the combustion of pulverized coal at high temperature ranging from about 1400; c to 1700; c [7]. The problem of fly ash disposal is only expected to get worse as the demand of energy grows [8]. The way to resolve the problem of fly ash use of those as a raw fabric for the production of valuable items. In this way there is the conservation of natural resources because the environmental aspect must be measured and estimated when thinking about social and economic development in other words, sustainability [9, 10]. Manufacture of fly ash based products such as cement, concrete blocks, bricks, panels or any other material or the use of fly ash in construction activity such as road laying, embankments, or use as landfill to recover low lying parts including mines back filling or pitheads or for any other use shall be carried out in accordance with specifications and guidelines laid down by the Bureau of Indian Standards, Indian Bureau of Mines (The gazette of India) [11]. Fly ash can be innovatively utilized as a resources material for cement [12, 13, 5], concrete [12, 13], brick [12-14], road construction [12, 13, 14, 5], agriculture [12, 13, 5, 15, 16], water and wastewater treatment [14, 5], mine backfill [5], road embankment [13] etc.

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Indian coal

Coal forms when dead plant matter is converted into peat, after that it is converted into lignite, then sub-bituminous coal, then turn into bituminous coal, and in last form anthracite [17]. Coal supplies a total of 55% of commercial energy production of India [18]. The Indian coal is classified into two categories – coking and non-coking.

Coking coal

Prime coking – Mostly utilized for metallurgical purpose.

Medium coking – Mostly utilized in steel industry.

Semi coking – Mostly utilized in cement, fertilizer and sponge iron industries.

- Non-coking coal: Non-coking coal includes lion's share of Indian coal. It is based on useful heat value (UHV), it is classified into grades A to G for commercial use. A to C grades are regarded as superior and are used in cement, fertilizer and sponge iron industries. D to G grade are accessible in almost in all the coalfields.
- Lignite: its common name is brown coal and is classified into grades A to C on the basis of gross calorific value. It is considered as apt fuel for generation of power due to its little ash content [19].

Coal of India has high ash content. The average ash content in Indian coal is 35-38% while ash content in imported coal 10-15%. In this regard, washing will help to decrease the ash content [20]. A high ash content coal also makes a number of problems for thermal power stations, including erosion in parts and materials, difficulty in pulverization, poor emissivity and flame temperature [21]. The estimation of coal resources in India reached to 301.56 billion tonnes in 2014.

Sector wise demand for coal in India

In 2013-2014 according to Annual Report 2013-2014 – Ministry of Coal, power is the biggest consumer of coal. It needs 76% of total coal while 11% coal is utilized by fertilizers. The third position is carried out by steel which use 7% coal and cement and sponge iron industry share only 3% and 3% continuously. Table 1 shows the sector wise demand of coal.

Table 1: Sector wise demand of coal

Sector	Demand (%)
Power plant	76%
Other fertilizers	11%
Steel industry	7%
Cement industry	3%
Sponge iron industry	3%

(Source: Annual Report 2013-2014 – Ministry of Coal)

Fly ash

The fly ash is a component of coal combustion residues (CCRs). CCRs include fly ash, bottom ash, boiler slag, flue gas desulfurization (FGD) residue and other fine solid particles [23]. Fly ash is a ferro-aluminosilicate material. The most usual ingredients found in fly ash include Si, Al, Fe, Ca, Mg, K and Na [24-25]. It is inorganic matter present in Indian coal solidifies while suspended in the exhaust gases and finally gets collected through an electrostatic precipitator due to this rapid solidification process [26]. Particles of fly ash are empty spheres (cenospheres) filled with smaller amorphous particles and crystals (plerospheres) [27]. Its colour depending upon the carbon content varies from light tan to dark [28]. However, the fly ash composition mostly depending on the geographical factors related to coal deposit, combustion conditions and fly ash collection devices. The major chemical composition found in fly ash are primarily SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO which makes total 95-99% constituent while minor constituents are TiO_2, Na_2O, K_2O, and SO_3 comprises 0.5-3.5%. The average chemical composition of Indian fly ash has been shown in Table 2 [29].

Table 2: The average chemical composition of Indian fly ash

Content	Pecentage by mass
CaO	0.37 - 27.68
SiO_2	27.88 - 59.40
Al_2O_3	5.23 - 33.90
Fe_2O_3	1.21 - 29.63
MgO	0.42 - 8.29
SO_3	0.04 - 4.71
Na_2O	0.20 - 6.90
K_2O	0.64 - 6.68
TiO_2	0.24 - 1.73
Loss-on-ignition	0.21 - 28.37

(Source- Feng X. et. al., 2011)

A number of researchers [30-33] have observed that decreasing fly ash particle size tend to increase in concentration with As, Cd, Cu, Ca, Mo, Pb, S, Sb, Se, Ti and Zn. Fly ash particles ranging in size from 0.5 to 300 microns in equivalent diameter, being light weight, have potential to get airborne easily and pollute the surroundings [34]. Fly ash is a pozzolanic material and delivers more strength than other construction materials. According to the percentage of the basic constituent, fly ash is classified into two categories as class C and class F.

Classes of fly ash

There are two classes of fly ash which are defined by (ASTM C618 2005); these are

Class ‘C’ fly ash and

Class ‘F’ fly ash. [35]

On the basis of aluminum oxide, silicon oxide, and iron oxide content of these two classes of fly ash is differentiated to each [1].

1. Class ‘C’ fly ash

Class ‘C’ fly ash is mostly generated by burning of sub-bituminous coal or lignite. CaO in Class ‘C’ fly ash is more than 10% and quantities of silica, iron and potassium oxides are also lower in Class ‘C’ [36].

2. Class ‘F’ fly ash

Class ‘F’ fly ash is commonly made by burning of anthracite or bituminous coal [43] having CaO less than 10%. The quantities of silica, iron and potassium oxides are also higher in class ‘F’ [36]. Fly ash react with water to produce cementitious compounds [13]. On the other hand alkali and sulfate (SO_4) contents are less in amount in class ‘F’ fly-ash [38]. Chemical composition of fly ash and ASTM C 618 specification requirement is shown in Table 3 [39].

Table 3: Chemical composition of fly ash and ASTM C 618 specification requirement

Chemical composition	Min/max	Class C	Class F
$SiO_2 + Al_2O_3 + Fe_2O_3$ (%)	min %	50	70
Sulpher trioxide (SO_3)	max %	5.0	5.0
Moisture content	max %	3.0	3.0
LOI	max %	6.0	6.0

(Source- Santos F. et. al., 2011)

Origin of fly ash

Fly ash is generated from the burning of pulverized coal in a coal fired thermal power plant. It is a powdery, fine-grained particulate material that is carried off in the flue gas and usually collected from the flue gas by means of bag houses, electrostatic precipitators or mechanical collection devices such as cyclones. Generally, three types of coal-fired boiler furnaces are used in the electric utility industry. These are cyclone furnaces, dry-bottom boilers and wet-bottom boilers.

Cyclone furnace where crushed coal is used as a fuel, 70 to 80% of the ash is retained as boiler slag and only 20 to 30% leaves the furnace as dry ash in the flue gas.

Dry-bottom furnace is the most common type of coal burning furnace. During the time of coal combustion in a dry-bottom boiler about 80% of ash is coming out from the furnace as fly ash, entrained in the flue gas.

When pulverized coal is burned in a wet-bottom furnace, approximately 50% of the ash is retained in the furnace and the other 50% being entrained in the flue gas.

Environmental problem related to fly ash

Environmental pollution due to the coal based thermal power plants all over the world is a serious problem and influencing the environment in terms of land utilization, health hazards air, land, and water in particular and thus leads to environmental dangers [40]. A large number of research works have been practiced to discover useful applications of fly ash utilization. The environmental impact of fly ash in term of its bulk generation, heavy usage of ground for disposal short and long term impact on surrounding countries is considerably experienced [41]. It may adversely affect the environment by calling up their hazardous component. So, its disposal and utilization is very much essential to prevent its contamination [42]. This large amount of fly ash is dumped in the vast areas of ash pond and is leading to serious environmental degradation due to the effect of leaching of toxic elements. During dry season it is carried out by the wind from ash pond areas and causes harsh respiratory diseases to surrounding population. At present the bulk utilization of unused ash is a grave issue for thermal power plant authorities due to requirement of huge land for the disposal of fly ash. On the other hand mining industry is also facing a big problem of scarcity of river sand due to its increasing application in civil engineering. As a result many underground coal mines are left without filling a suitable material after mining of coal leading to land subsidence. Thus, the mining industry is searching for an alternative mine-fill material which is available in the form of fly ash in adequate quantity at lowest cost [43].

Current status of fly ash in India

In India, higher amount of fly ash is being generated, as most of our energy demand is met through coal based thermal power stations. Its generation in the country has increased from 40 Mn t/yr in 1994 to about 220 Mn t/yr in 2012. It is projected to be 350 Mn t/yr in 2017, 500 Mn t/yr in 2022 and

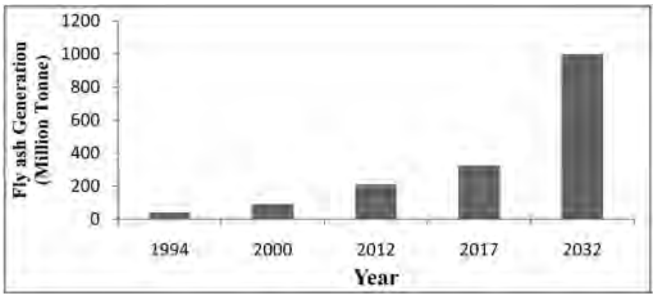

Fig 1. Fly ash generation at different years in India (Source: Annual report 2012-2013- Department of Science & Technology)

1000 Mn t/yr in 2032. The fly ash generation is expected to raise further as coal would keep on to remain as major source of energy. The fly ash, which is a resource material, if not managed well, may pose challenges to environment. Fig.1 shows fly ash generation at different years in India.

It has been proved to be a useful material and collective efforts initiated under Fly ash Mission of Government of India (1994) have lead to utilization of 120 Mn t/yr in 2012 as against 1 Mn t/yr in 1994. The percentage utilization of fly ash in different sectors for the years 1994 and 2012 is shown in Table 4.

TABLE 4: THE PERCENTAGE UTILIZATION OF FLY ASH IN DIFFERENT SECTORS FOR THE YEARS 1994 AND 2012.

Utilization area	1994	2012
	Total utilization - 1Mnt	Total utilization - 110 Mnt
Cement manufacturing	89%	47%
Low lying area filling	10%	10%
Brick manufacturing	1%	5%
Cement substitution	-	9%
Road embankments	-	9%
Ash bund raising	-	7%
Mine fill	-	12%
Agriculture and others	-	1%

(Source: Annual report 2012-2013 – Department of Science & Technology) [44]

Fly ash utilization

FLY ASH IN MANUFACTURE OF CEMENT

The maximum use of fly ash in India is cement manufacturing industries [45]. In the current years fast development of technology, demand of cement is rapidly increasing day by day [46]. Due to pozzolanic property of fly ash, it is used in cement replacement [47] and another reason during the production of 1 tonne of cement release 1 tonne of CO_2 into the air [48]. If we replace Portland by mineral byproducts such as fly ash significantly reduce CO_2 emission [49]. The fly ash utilization in cement industry has increased from 2.45 million-tonnes in 1998-99 to 41.33 million-tonnes in 2012-13 [50]. According to ASTM C618, fly ash belongs to class 'F' if (SiO_2+Al_2O_3+Fe_2O_3) > 70% and belongs to class 'C' if (SiO_2+Al_2O_3+Fe_2O_3) > 50% [51]. Both these fly ashes undergo pozzolanic reaction with lime (calcium hydroxide) created by hydration of cement and water to form calcium silicate hydrate like cement [52].

Fly ash for roads embankments

India produces a huge amount of waste materials as by-products from different sectors like industrial, agriculture, construction etc. These waste materials if not deposited safely it becomes hazardous. These hazardous waste utilized in the road construction sector [53] The presence of high content of calcium and silicate oxides the fly ash is used for stabilizing roads. The road constructed by fly ash gives high compression strength and thus pozzolanic properties [54-55]. Road plays a important part in the growth of the nation. They are a lifeline, offering a tranquil flow of man and material [56]. The fly ash use in highway embankments and fills is the second highest use of fly ash because it behaves like a fine sand material [57]. When fly ash is used for highway embankment or fill material some of the engineering properties of fly ash are its particle size distribution, shears strength and permeability are important [58]. The specific gravity of fly ash particles varies from 2.1 to 2.6 with an average of about 2.4 and grain size distribution of ash particles fall within the silt range with small percentage in the fine sand which is best for road embankment [28]. The best soil substitute with superior shear strength proves by fly ash [59] and permeability data for road construction of fly ash has been shown to range from about 10 -5 to 10 -9 cm/s or lower [60]. Hence, the use of fly ash for backfilling retaining walls or for constructing embankments, enlisting the following characteristics:

- low unit mass
- low compressibility
- high internal angle of friction
- ease of compaction
- reduced settlement when used as fill material
- self-hardening properties [59].

Fly ash in mine filling

Fly ash can be used in mine back fill, landfill, opencast mine filling and land reclamation [5]. The research suggests that the placement of fly ash at the mine site is good for the environment and human health both and in most cases its placement has no negative force [61-62]. To match this goal of effective transit of the fly ash and creation of the fill with acceptable strength characteristics are the two chief topics that need care [63-64]. Due to lighter colour and the lower carbon content fly ash is best for utilization in mine filling [65].

Possible areas of ash utilization in mines:

- filling of voids in opencast mines
- stowing of underground mines
- laying of haul roads

Fly ash in brick

For the manufacturing of building products like bricks, blocks, tiles etc fly ash is being important due to saving of fertile topsoil [45]. On examining a number of brick demand in the current years, different waste materials like rice husk, wood ash, fly ash even cement was applied to manufacture bricks. The bricks made with fly ash are stronger than other bricks [66]. The policy guidelines in India restrict the use of topsoil for building materials and encourage the exercise of at least 25% ash in clay bricks made up within a radius of 100 km from coal and lignite based thermal power stations [4]. In the year 1998-99, 0.70 million-tonnes of total fly ash generated in India was used for making of fly ash based bricks/blocks/ tiles etc which increased to 9.98 million-tonnes in the year 2012-13 [67]. Depending on the type of soil, fly ash (20- 50%) is used along with clay to produce clay bricks, which 40-45% porous than fly ash bricks. Clay fly ash bricks have high strength and absorb less water compared to bricks of fly ash [12].

Fly ash in agriculture

The attributes of soil as influenced by fly ash application has been looked at by various workers [68-74] for utilizing this industrial wasteland as an agronomic amendment. Fly ash has great potential in farming due to its efficacy in modification of soil health and crop yield [1]. The bearing of all important plant nutrients such as N, P, K, Mg, Ca, S and micronutrients make it a source of plant nutrients and increases yield of various crops when it use [75-78]. Utilization of fly ash in agriculture provides a more serious alternative for its safe disposal to improve the crop productivity and raise the land environment [79]. Fly ash, carrying both the nutrient-enriching and soil amending properties, which helpful in improving crop progress and give way in low fertility acid lateritic soil [80]. The Indian fly ash is alkaline in nature; so it uses in application of neutralize acidic soil by increases the soil pH [81]. Researches have demonstrated that the use of fly ash as a liming agent in acid soils may improve soil properties and increase crop production [82].

Fly ash in prestressed concrete

And also a number of results has been reported on the use of class F fly ash in concrete [83-96] but there is not much literature available on the use of class F fly ash as partial replacement of fine aggregates [92-96]. When concrete containing fly ash is appropriately cured, fly ash reaction products fill in the spaces between hydrating cement particles, thus bringing down the concrete permeability to water and aggressive chemicals [117]. The fly ash use in the concrete generally, decreases the bleeding, hydration temperature and permeability of the hardened concrete, increases the workability of the fresh concrete, resistance of the concrete to the chemical effects, and reduces the costs [98-101].

Fly ash in concrete has major benefits:

1. Increasing the lifetime of concrete roads and structures by getting better concrete durability.

2. Net drop in energy use and greenhouse gas [102].

WATER AND WASTEWATER TREATMENT

The use of fly ash to treat domestic [103] as well as industrial wastewater [104-106] and toxic metals [107-110] acts as adsorbent for removal of industrial waste like dyes has also been extensively studied. Fly ash based low cost absorbent was prepared, characterized and utilized for the removal of dyes such as Methyleneblue and Congo red from wastewater [111].

Presently, many of researchers are using fly ash as an adsorbent for the removal of various pollutants.

The capability of fly ash also shows by removing As (V) (98- 100%) and treated water has neutral pH [105]. At 6.5 pH, fly ash can remove fluoride (up to 94%) [106]. Fly ash in combination with kaoline can be successfully used to remove Cr (VI) at high temperature and low pH [110]. Viraraghan 1993 introduces comparative review but using pea gravel, medium sand, bottom ash and fly ash-bottom ash mixture seeking for reduction of COD and TSS [112].

Conclusions

Coal is used widely in thermal power plant for production of electricity and generates large amount of fly ash. Coal based thermal power plants all over the world is referred to be one of the main causes of pollution affecting environment in terms of land use, health hazards and air, soil and water in particular and thus leads to environmental dangers. So, the utilization of fly ash from thermal power plant is essential to save our environment. Fly ash is the important raw material for various industrial and construction applications. It is mostly utilized in manufacturing of bricks, prestressed concrete, cement, roads/embankments and agriculture. This waste has found application in water and wastewater treatment. It is advisable to explore all possible applications for fly ash utilization. The utilization of fly ash gives good result in almost every aspects including good strength, economically feasible and environmental friendly.

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