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Industrial Applications of Fly ash: A Review

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Abstract— **This paper presents a general review on the applications of the so-called 'fly ash' derived from the combustion of fossil coal for energy production. The main applications of fly ash are then discussed, with particular reference to disposal as well as to civil engineering, chemical industries, agricultural, environmental and soil stabilization applications of fly ash. In future fly ash can be used as substitute for materials and it remains a potential low-cost adsorbent for the future. From the review of various applications of flyash it can be concluded that flyash is very good alternative to conventional activated carbon and can replace activated carbon in many preocesses in order to minimize the cost. It finds wide application in agreecultural,civil and other areas.**

Index Terms*—: Fly *ash, cement industries, chemical industries, environmental and soil stabilization

I. Introduction

Coal-based thermal power stations have been operated for more than 50 years in India, but the concept of developing environment-friendly solutions for fly ash utilization is major concern now a days. Overall fly ash utilization in India stands at a fairly low level of about 15% of the quantity generated. Several factors to be considered for fly ash utilization in India, among numerous factors that account for the low level of utilization, are listed as follows:,a.Poor understanding of the chemistry of fly ash and its derivatives for proper end applications. b.Absence of standards and specifications for fly ash products. c.Lack of reliable quality assurance for fly ash products Poor public awareness about the products and their performance. d.Non-availability of dry fly ash collection facilities Easy availability of land with top soil at cheap rates for manufacturing conventional bricks. e.Lack of proper coordination between thermal plants and ash users.Fly ash utilization in the country is gaining momentum owing to the stringent regulations that the Ministry of Environment and Forests, Government of India has stipulated, as also to increased awareness about the benefits of using fly ash for various products [1-3]. Fly ash from coal-fired thermal power stations is an excellent potential raw material for the manufacture of construction material like blended cement, fly ash bricks, mosaic tiles and hollow blocks. It also has other, high volume applications and can be used for paving roads, building embankments, and mine fills. Fly ash products have several advantages over conventional products. The use of cement in the manufacture of construction products can be reduced by substitution with fly ash. While the use of cement cannot be completely avoided, for certain products like tiles, the substitution can go up to 50 per cent. These products are known to be stronger and more cost-effective because of substantial savings on raw material. Full utilization of generated fly ash in India, will provide employment potential for 3000 people. The fly ash has been utilized in different ways as discussed in [4, 5, 6].Various possibilities for its use are under research and few of them are discussed as follows:

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II.FLY ASH IN CEMENT INDUSTRIES

A. *Fly ash as Fill Material*

Large scale use of ash as a fill material can be applied where

- Fly ash replaces another material and is therefore in direct competition with that material.
- Fly ash itself is used by the power generating company producing the fly ash to improve the economics of the overall disposal of surplus fly ash.

Fly ash disposal is combined with the rehabilitation and reclamation of land areas desecrated by other operations. Fills can be constructed as structural fills where the fly ash is placed in thin lifts and compacted. Structural fly ash fills are relatively incompressible and are suitable for the support of buildings and other structures. Non-structural fly ash fill can be used for the development of parks, parking lots, playgrounds and other similar lightly loaded facilities.

One of the most significant characteristics of fly ash in its use as a fill material is its strength. Well-compacted fly ash has strength comparable to or greater than soils normally used in earth fill operations. In addition, fly ash possesses self-hardening properties which can result in the development of shear strengths. The addition of cement can induce hardening in bituminous fly ash which may not self-harden alone. Significant increases in shear strength can be realized in relatively short periods of time and it can be very useful in the design of embankments.

B. *Fly ash in Concrete*

Fly ash in concrete has significant benefits including:
1.increasing the life of concrete roads and structures by improving concrete durability.2.net reduction in energy use

and greenhouse gas and other adverse air emissions when fly ash is used to replace or displace manufactured cement.

C. Fly ash in Portland cement concrete

Fly ash can be used in Portland cement concrete to enhance the performance of the concrete. Portland cement is manufactured with calcium oxide (CaO), some of which is released in a free state during hydration. As much as 20 pounds of free lime is released during hydration of 100 pounds of cement. This liberated lime forms the necessary ingredient for reaction with fly ash silicates to form strong and durable cementing compounds, thus improves many of the properties of the concrete. Some of the resulting benefits are: be disposed in landfills, and conservation of other natural resources and materials. Typically, 15 to 30 % of the Portland cement is replaced with fly ash.

D. Fly ash for Roads

Fly ash can be used for construction of road and embankment. This utilization has many advantages over conventional methods.

1.Saves top soil which otherwise is conventionally used

2.Avoids creation of low lying areas (by excavation of soil to be used for construction of embankments)

3.Avoids recurring expenditure on excavation of soil from one place for construction and filling up of low lying areas thus created.

4.Does not deprive the nation of the agricultural produce that would be grown on the top soil which otherwise would have been used for embankment construction.

5.Reduces the demand of land for disposal/deposition of fly ash that otherwise would not have been used for construction of embankment.

E. Fly ash Bricks

Fly ash products are also environment-friendly. A case in point is fly ash bricks. The manufacture of conventional clay bricks involves the consumption of large amounts of clay. This depletes topsoil and degradation of agricultural land. Fly ash bricks do not require clay and serve two purposes; preservation of topsoil and constructive utilization of fly ash. Fly ash bricks are made up of fly ash, sand and cement. In these bricks fly ash is used as the primary filler and sand is added as secondary filler. Cement is used to binder, which helps in holding all the raw material together. Bricks can be mainly grouped into two categories:

1.Fly ash bricks using cement as a binder: Raw materials include: fly ash, cement and sand.

2.Fly ash brick using lime as a binder: Raw materials include: fly ash, lime gypsum and sand.

F. Fly ash Product-Mosaic tile

Mosaic tile are manufactured utilizing the fly ash. The process involves preparing the mix for two layers: the wearing layer and the base layer. The wearing layer consists of a plastic mix of mosaic chips, cement, and fly ash and dolomite powder. The base layer consists of a semi-dry mix of fly ash, cement and quarry dust. The tiles are pressed in the tile-making machine and air-dried for 12 hours or more. They then undergo curing in water tanks for 15 days. The tiles are then polished and stacked for supply.

G. Light Weight Aggregates

Worldwide, many technologies have been developed for the production of artificial aggregates from fly ash. Only two of them have reached the commercial status-the sintering process Lytag and the cold-bonded process Aardelite. Aggregates from fly ash produced can be used for a variety of applications in the construction industry, including masonry elements, precast concrete elements, ready-mix concrete for buildings up to five floors and bituminous concrete for road foundation.

III. FLY ASH IN AGRICULTURE

Research on agricultural uses of fly ash has been going on in universities and research institutes across the country for several years. The same fly ash that causes harm when it settles on leaves can prove beneficial when applied scientifically to agricultural fields. It can be a soil modifier and enhance its moisture retaining capacity and fertility. It improves the plant's water and nutrient uptake, helps in the development of roots and soil-binding, stores carbohydrates and oils for use when needed, protects the plants from soil-borne diseases, and detoxifies contaminated soils. Yields are also known to increase, as experiments on groundnut, sunflower, linseed and other oilseeds have shown.

A. Fly ash for Soil Stabilization

Soil stabilization is the permanent physical and chemical alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and/or control the shrink-swell properties of a soil, thus improving the load-bearing capacity of a sub-grade to support pavements and foundations. Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials. Stabilization can be achieved with a variety of chemical additives including lime, fly ash, and Portland cement, as well as by-products such as lime-kiln dust (LKD) and cement-kiln dust (CKD). Proper design and testing is an important component of any stabilization project.

This allows for the establishment of design criteria as well as the determination of the proper chemical additive and admixture rate to be used to achieve the desired engineering properties. Benefits of the stabilization process can include: Higher resistance (R) values, Reduction in plasticity, Lower permeability, Reduction of pavement thickness, Elimination of excavation - material hauling/handling - and base importation, Aids compaction, Provides “all-weather” access onto and within projects sites.

Another form of soil treatment closely related to soil stabilization is soil modification, sometimes referred to as “mud drying” or soil conditioning. Although some stabilization inherently occurs in soil modification, the distinction is that soil modification is merely a means to reduce the moisture content of a soil to expedite construction, whereas stabilization can substantially increase the shear strength of a material such that it can be incorporated into the project’s structural design.

The determining factors associated with soil modification vs soil stabilization may be the existing moisture content, the end use of the soil structure and ultimately the cost benefit provided. Equipment for the stabilization and modification processes include: chemical additive spreaders, soil mixers (reclaimers), portable pneumatic storage containers, water trucks, deep lift compactors, motor graders.

IV. FLYASH IN CHEMICAL INDUSTRY

A. Fly Ash Based Polymer Composites as Wood Substitute

Fly ash based composites have been developed using fly ash as filler and jute cloth as reinforcement. After treatment, the jute cloth is passed into the matrix for lamination. The laminates are cured at specific temperature and pressure. Numbers of laminates are used for required thickness. The technology on fly ash Polymer Composite using Jute cloth as reinforcement for wood substitute material can be applied in many applications like door shutters, partition panels, flooring tiles, wall paneling, ceiling, etc. With regard to wood substitute products, it may be noted that the developed components / materials are stronger, more durable, resistant to corrosion and above all cost effective as compared to the conventional material i.e. wood.

This technology has been developed by Regional Research Laboratory, Bhopal in collaboration with Building Materials and Technology Promotion Council (BMTPC), New Delhi and Technology Information, Forecasting and Assessment Council (TIFAC), New Delhi. One commercial plant has also been set up based on this technology near Chennai.

B.Fly ash as an Adsorbent

In recent years, utilization of fly ash has gained much attention in public and industry, which will help reduce the environmental burden and enhance economic benefit. The technical feasibility of utilization of fly ash as a low-cost adsorbent for various adsorption processes for removal of pollutants in air and water systems has been reviewed.

Instead of using commercial activated carbon or zeolites, a lot of researches have been conducted using fly ash for adsorption of NOx, SOx, organic compounds, and mercury in air, and cations, anions, dyes and other organic matters in waters. It is recognized that fly ash is a promising adsorbent for removal of various pollutants. Chemical treatment of fly ash will make conversion of fly ash into a more efficient adsorbent for gas and water cleaning.

Wang and Wu [7] investigation studies also revealed that unburned carbon component in fly ash plays an important role in adsorption capacity. There are many research reports on work that have been carried out in the field of adsorption techniques for the removal of toxic metal ions, pollutants in air, organic and inorganic compounds, and dye adsorption, in wastewater using fly ash as adsorbent.

C.Removal of Phenol and its Derivatives

Organic pollutants, such as phenolic compounds, pesticides, and dyes, etc., can be removed very effectively using fly ash as adsorbent [8]. The fly ash adsorbed 67, 20, and 22 mg/g for phenol, chlorophenol, and 2, 4-dichlorophenol, respectively, for the highest water phase concentrations used [9]. Phenol displayed a much higher affinity for fly ash than 3-chlorophenol and 2, 4 dichlorophenol [11].

Removal of 2,4-dichlorophenol and pentachlorophenol from waters by sorption using coal fly ash from a Portuguese thermal power plant was studied and observed that fly ash exhibited more affinity towards the sorption of pentachlorophenol, in comparison to 2,4-dichlorophenol [12]. Batch shaking adsorption experiments were conducted to estimate potentiality of fly ash and impregnated fly ash in removing phenols from aqueous solution and found that impregnated fly ash has shown better efficiency of phenol removal than fly ash [44].

Dried activated sludge and fly ash as a substitute for activated carbon was examined in this study for the removal of phenol. The maximum phenol loading capacity of each sorbent was found to be 91.0 mg/g for dried activated sludge, 27.9 mg/g for fly ash and 108.0 mg/g for granular activated carbon at 100 mg/l initial phenol concentration [13]. Chlorophenol in the wastewater were also removed efficiently through a fly ash column, with breakthrough times being inversely proportional to flow rates [14].

Adsorbent prepared from fly ash was successfully used to remove cresol from an aqueous solution in a batch reactor. The adsorbent was characterized, and significant removal of cresol was achieved [15].Coal fly ash was successfully used to remove 2, 4-dimethyl phenol from aqueous solutions and the rate of adsorption follows first order kinetics before attaining equilibrium. Equilibrium adsorption data satisfied both Langmuir and Freundlich isotherms [16].

D. Removal of Other Organic Compounds

Batch studies were carried out to investigate the removal of organic acids by adsorption on fly ash impregnated with hydroxides of Al, Cd, Cu, Fe and Ni. The percentage removals of cinnamic acid, indole-3-acetic acid, β-napthaleneacetic acid, β-naphthoxyacetic acid, oxalic acid and trichloroacetic acid from water were 75%, 63·63%, 100%, 95·25%, 85·71% and 78·26%, respectively [17] Batch adsorption studies of organic pollutants containing carbosyl group on activated charcoal, fly ash and granular charcoal are made.

The adsorption capacity of activated charcoal, fly ash and granular charcoal is 39.6, 39.6 and 28.8 mg/g respectively. The adsorption data recorded are well fitted in Freundlich adsorption isotherm. The experimental results obtained suggest the possible use of fly ash in water treatment processes for the removal of organic pollutants [18, 19, 20, 21, 22, 23, 24].

E.Removal of Inorganic Components

Hexavalent chromium has been separated from an aqueous solution by fly ash [25]. Adsorptions of heavy metal cations using Brazilian coal fly ash modified by hydrothermal method were studied. The adsorption properties of synthetic zeolite produced from Brazilian coal fly ash were investigated for some heavy metal cations (Zn, Cu, Mn and Pb).The batch method has been employed, using metal concentrations in solution ranging from 100 to 3000 mg/l. Results lead to the conclusion that a hydrothermal treatment can increase from 2 to 25 times the adsorption capacity of the coal ash comparing to its original capacity.

The adsorption increases as cation concentrations in aqueous solution increases and the preference order observed for adsorption is Pb > Cu > Zn > Mn [26]. Fly Ash and activated carbon were used in the removal of Cu_2^+ and Ni_2^+ ions from aqueous solutions. The adsorption capacities were 7.0 mg/g for Cu^{2+} , 5.9 mg/g for Ni^{2+} for fly ash, and 6.9 mg/g for Cu^{2+} , 5.4 mg/g for Ni^{2+} for activated carbon [27]. Fly ash was used for the removal of Mn (II) from aqueous solutions and wastewaters.The removal was found to be highly concentration dependent and higher removal (%) was obtained at low concentrations of Mn (II) in the solutions.

The ability of natural rice husk and fly ash was tested in removing Cr (III) ion from aqueous solution and industrial wastewater and found that Cr (III) ion from industrial wastewater sample with a concentration of 50 ± 2 mg/L was removed by natural rice husk and fly ash with 92.78% and 85.24%, respectively [28]. Adsorption of mercury (II) on coal fly ash conforms to Freundlich's adsorption model. There was total adsorption of mercury below 10 mg l^{-1} [29].

F..Removal of Dye

The feasibility of using fly ash as an alternative to activated carbon was examined for colour removal from synthetic dye solutions [30]. The removal of some common textile dyes using the fly ash samples has been investigated spectrophotometrically as a function of fly ash dosage, dye concentration, and contact time at ambient conditions. Adsorption studies using a visible light irradiated system have been performed, and the spectral analysis of the photolyzed solution revealed that decoloration of the concerned dyes was greater compared to that observed in the dark under identical experimental conditions [31].

The removal of chrome dye from its aqueous solutions by adsorption on a homogeneous mixture of fly ash and coal in different proportions has been carried out and 100% removal of the said dye was achieved at 10 $mg1^{-1}$, 30°C, 2.0 pH and 53 μm particle size, using a 1:1 ratio of fly ash and coal [32]. Adsorption studies were made in treating textile dyeing industrial effluent containing Methylene blue and Congo red textile dyes by using fly ash. The first-order adsorption rate constants were determined and found decreasing with temperature [33].

G..Pesticide

Adsorption of carbofuran on fly ash was studied at 25°C and 50°C. The data were analysed and the data fit in close agreement with the Freundlich equation [34]. Malathion from Aqueous Solutions and Waste Water was removed by using Fly Ash as adsorbent [35].

H.Removal of Air pollutant

Zeolites X, Y, and Na-P1 (90 °C) and analcime and sodalite (150 °C) were synthesized from Class F fly ash using 3 M sodium hydroxide solutions and autogenous pressures The dried samples were evaluated for their ability to absorb sulfur dioxide (SO_2) from a simulated stack gas containing 2000 ppm SO_2. A 7 day 150 °C cured sample containing analcime and sodalite was able to adsorb 6−7 mg of SO_2 per gram of sample regardless of the source of the fly ash, whereas a 90 °C cured sample containing X, Y, and Na-P1 was significantly less efficient [36-37].

I.Removal of Chemical Oxygen Demand (COD)

Fly ash, brick kiln ash and commercial activated carbon was used in the reduction of chemical oxygen demand (COD) from domestic wastewater. Starting with an initial COD concentration of 1080 mg/l the maximum COD reduction achieved for fly ash was 87.84%, brick kiln ash was 83.22% and commercial activated carbon was 99.35 %. These values were achieved when the wastewater was treated with activated carbon for 180 min, fly ash 250 min and brick kiln ash 300 min and the adsorbent dose was kept respectively at 40 g/l, 60 g/l and 45 g/l for activated carbon, fly ash and brick kiln ash [38, 39,40,41].

V.Conclusion

The literature review revealed that fly ash finds a numerous application in the cement industries, agricultural field, polymer industries and in pollution control. Due to limited water resources and increasing pollution levels, many methods are used for removing pollutants from wastewater, and among them, the adsorption method is widely used because it is versatile as it removes diverse pollutants.

The various chemical plants treating wastewater through adsorption, activated carbon is frequently used as an adsorbent. However, in view of the higher cost of activated carbons and difficulties associated with regeneration, attempts have been made by various workers to use fly ash as low-cost materials and it remains a potential low-cost adsorbent for the future.

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