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Review Article

FLY ASH GENERATION-UTILIZATION, GOVERNMENT INITIATIVES IN INDIA AND OTHER DIVERSE APPLICATIONS: A REVIEW

Rekha Sharma*, R. N. Yadav

Department of Chemistry, Govt. R. R. (PG) College, Alwar, Rajasthan, India

**Corresponding author: rsrekha19@gmail.com*

ABSTRACT

The dynamic economic growth, robust growth of industrialization and expanding population are the key factors responsible for significant increases in global energy demand. The Power sectors account for almost 74% of coal consumption in India. The Indian coal is characterized by low calorific value (3000-3500 k. cal.) and very high ash content (30-45 %). Thus, huge amount of fly ash is being generated every year as "waste by product" in coal-based power plants. Hence in present scenario, the safe management and eco-friendly utilization of this surplus fly ash generated has become a global challenge. Due to the serious efforts of 'Fly Ash Mission' of India, the utilization level of fly ash has progressively improved from 11.68 % in 1998-99 to 77.59 % in 2018-19. This review presents state wise status of fly ash generation-utilization, government initiatives in India and other new domains of potential fly ash applications.

Keywords: Energy demand, Thermal Power Plants, Fly Ash, Waste by product

1. INTRODUCTION

India holds seventh position in world's fastest growing economies and has world's second largest population after China [1]. The energy consumption in country has become just more than double during the past two decades. Currently India is the third largest energy consumer in the world after China and US [2]. This is exerting immense pressure on thermal power plants to generate more and more electricity every year to cope with increased energy demands. According to 69th edition of the 'BP Statistical Review of World Energy 2020 Report', global reserves for anthracite and bituminous coal are 749.17 billion tons and for sub bituminous and lignite are 320.47 billion tons [3]. Our country is blessed with vast coal reserves which constitute 9.9 % of the global coal reserves. With 100.86 billion tons of anthracite and bituminous coal and 5.08 billion tons of sub bituminous and lignite coal, it has fifth largest "proved coal reserves" in the world. India ranks second in world's thermal coal production and it is the second largest coal consumer also [1,4]. Owing to its large abundance and being a cheaper fossil fuel in comparison to other fuels, coal is the most extensively utilized fossil fuel in India and worldwide and will remain so till 2031-32 and possibly beyond [3,5]. Coal contributes 44 % of the total primary energy supply and 74 % of the total electricity generation in India [6].

The Indian coal is characterized by low calorific value (3000-3500 k. cal.) and very high ash content (30-45 %). Thus, huge amount of fly ash is being generated every year as "waste by product" in coal-based power plants [7]. The power plant ashes (or coal ashes) are generated as a mixture of coarse bottom ash (20 %) or finer pozzolanic fly ash (80 %) [8]. These are carried away by flue gases and are captured by electrostatic precipitators in the boiler. The word "pozzolanic" refers to the capacity of fly ash to react with lime and water at ambient temperature to form a solid cement like substance, insoluble in water [9]. Conventionally fly ash is disposed in dry/wet condition in ash ponds or ash dykes. Disposal in wet or slurry form currently occupies nearly 40,000 hectares of land with 1040mn m^3 of water required annually and it also degrades pozzolanic property of fly ash [8, 10]. In India current annual production of fly ash is 112 million tons which requires 6500 hectares of land for its disposal. The ministry of power, government of India estimates 1800 million tons of coal use every year and 600 million tons of fly ash generation by the year 2031-32 [10]. This surplus fly ash stock is posing a great threat in terms of precious land required for its disposal, detrimental impacts on environment and its inherent potential to cause health hazards [11-12]. Hence in present scenario, the safe management and substantial utilization of this surplus fly ash generated, has become a global challenge.

2. TYPES AND CHEMICAL COMPOSITION OF FLY ASH

Chemically fly ash is an inorganic ferroaluminum-silicate mineral which is amorphous in nature [13]. Fly ash is a heterogeneous mixture of various oxides with SiO_2, Al_2O_3, Fe_2O_3 and CaO being the chief chemical components. It contains heavy metals in trace concentrations similar to those present in unpolluted soil [14]. Commonly found metals are arsenic (As), beryllium (Be), boron (B), copper (Cu), cadmium (Cd), cobalt (Co), chromium (Cr), lead (Pb), mercury (Hg), molybdenum (Mb), nickel (Ni), selenium (Se), thorium (Th), uranium (U), vanadium (V), zinc (Zn) [9, 15]. Fly ash also exhibits diverse minerology. The chief phases constituting fly ash are amorphous glass phase together with quartz, mullite and iron oxides such as hematite and magnetite. Calcium rich fly ashes may contain minerals like calcium silicates and calcium aluminates similar to those present in Portland cement [16]. After combustion of coal, fly ash generated is found to contain 10 % magnified concentrations of these elements than the parent coal [11, 16].The heavy metals present in fly ash are toxic in nature and have a tendency of leaching into ground/surface water by percolating through soil and to pollute it [17]. Depending upon the source and chemical composition of the coal used, fly ashes are broadly classified into two classes by the American society for testing and material specification (ASTM C618) [18]. Class-F or siliceous fly ash is produced by combustion of anthracite/bituminous coal. It has less than 7 % calcium oxide. Class-C or calcareous fly ash is produced by burning of lignite/sub-bituminous coal and possess self-cementing properties due to elevated calcium oxide contents (>20%). Table 1 displays differences between the two classes of fly ash.

Table1: Types and Chemical Composition of Fly Ash.

Compounds	Class-C	Class-F
$SiO_2 + Al_2O_3 + Fe_2O_3$	50-70 %	More than 70 %
CaO	More than 20 %	Less than 7 %
MgO	5	2
SO_3	3	1
Cementing agent required	No	Yes (Portland cement, quick lime etc.)
Property Possessed	Pozzolanic and self-cementing.	Pozzolanic.
Source of Coal	Sub Bituminous and Lignite Coal.	Anthracite and Bituminous Coal.

3. GLOBAL FLY ASH GENERATION-UTILIZATION

Coal is being used worldwide as a primary fossil fuel for generation of electricity in thermal power plants. As a result, quantum of fly ash produced is also increasing every year and its safe management is posing a major challenge especially in developing countries. Fly ash generation-utilization in million tons (MT) of different countries has been summarized below in table 2 (fig. 1). It is evident from the table 2 that three countries have annual fly ash generation more than 75 %.India with 112 MT of annual ash production ranks first followed by China (100 MT) and USA (75 MT) worldwide. While annual ash utilization is 38 % in India, 45% in China and 65 % in USA. Three countries namely Germany, UK and Australia have ash production in the range 10 MT to below than 50 MT and ash utilization in the range 50-85 %. Denmark, Italy and Netherland which have shown 100 % ash use annually, generates insignificant amounts of ash.

Table 2: Worldwide Fly Ash Generation (MT)-Utilization (in %) [12, 19]

Name of the Country	Annual Fly Ash Generation (MT)	% Fly Ash Utilization
India	112	38
China	100	45
USA	75	65
Germany	40	85
Russia	26.7	18
UK	15	50
Australia	10	85
Canada	6	75
France	3	85
Denmark	2	100
Italy	2	100
Netherland	2	100

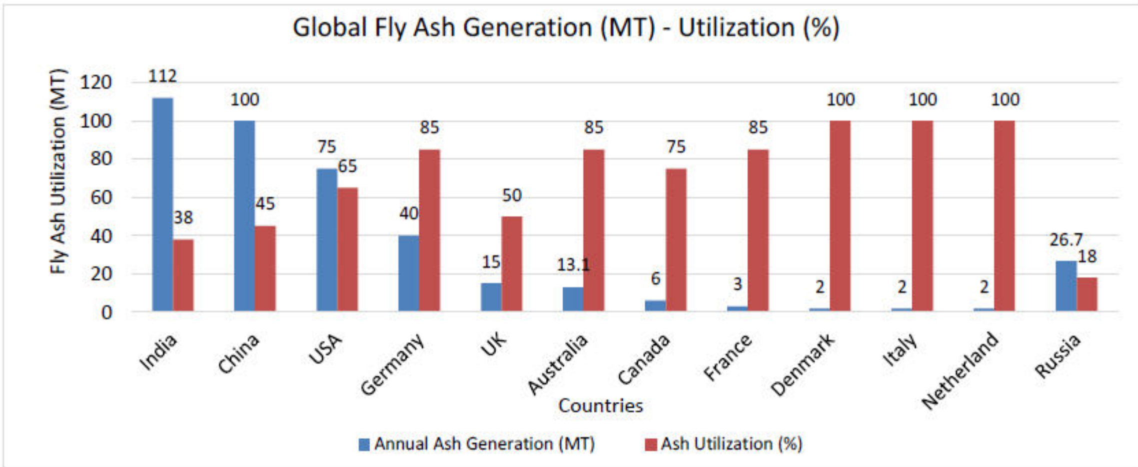

Fig.1: Worldwide Fly Ash Generation-Utilization. *Source of data [12, 19]*

4. FLY ASH GENERATION-UTILIZATION IN INDIA: FLY ASH MISSION

The "Fly ash Mission" of Government of India, introduced during 1994, is a joint effort of Ministry of Power (MOP), Ministry of Environment, Forests and Climate Change (MoEF& CC) with Department of Science and Technology (DST) being the nodal agency. The aim of thispilot project is to promote gainful utilization and safe management of fly ash rather than its disposal in ash ponds. As a result, fly ash earlier considered as "hazardous waste material" is now being treated as "valuable resource material and saleable commodity" [8, 13]. Various notifications and policies have been issued by it. Some important features of it have been discussed below [6, 8, 20].

4.1. The 1st fly ash notification issued by the Ministry of Environment, Forests and Climate Change (MoEF & CC) in year 1999, which has been amended in 2003, 2009, and 2016. All coal/lignite based Thermal power plant's (TPP's) in country have been given targets of 100 % fly ash utilization in a time bound phased manner. Thermal power plant's setup before the date of notification (3 Nov. 2009) will have to achieve 50 % within one year, 60 % within two years, 75 % within three years, 90 % within four years and 100 % within five years. New TPP'S shall achieve 50 % in one year, 70 % in two years, 90 % in three years and 100 % in four years.

4.2. All building materials (*i.e.* cement, concrete, bricks, blocks) and any type of constructions (*i.e.* dams, dykes, roads) will utilize only fly ash- based products within a radius of 300 Kms. from thermal power plants.

4.3. According to amendment 2016, to encourage maximum utilization of fly ash, it has been made mandatory for power plants to bear the entire cost for ash transportation up to 100 Kms. and for distances 100-300 Kms., the cost will be equally shared between TPP's and user. It has also been made compulsory that in all asset creation program of government including construction of roads, dams, flyovers, buildings, within 300 Km. distance from TPP's, entire cost would be paid by TPP's themselves.

4.4. The 2009 notification clearly directs that within a radius of 300 Kms. of a coal / lignite based TPP, any compaction and reclamation of low-lying areas should be done by using fly ash only according to the specifications/guidelines laid down by authorities. No soil will be used in such cases.

4.5. According to the draft amendment of 2019, installation of new red clay brick kilns within a radius of 300 Kms. from a TPP has been restricted and such pre- existing kilns will be converted into fly ash-based products manufacturing units. To encourage such conversion, TPP will have to provide at least 20 % fly ash to units manufacturing bricks, tiles etc. on priority basis over other users at a nominal rate of Rs. 1 per ton. For building materials minimum fly ash content, to qualify as fly as-based product, has been specified as 15-50 % I. S. (Indian Standard Specifications).

4.6. For strict monitoring of fly ash disposal and to minimize pollution by it, the MoEF& CC has imposed an additional condition for TPP'S.

4.7. In order to prevent embankment failures and flyash flow into the water body, there should be provision of a clearance area of at least 500 meters from a river/water body, in case of fly ash disposal in abandoned mines. Its top layer should contain at least 70 cm overburden of gravel/stones followed by 30 cm. sweet soil cover and this should be used for raising vegetation subsequently.

4.8. Only the decanted water from mines, treated sewage water and make up water from treated effluents such as cooling tower blow down should be used for preparing slurry.

4.9. For effective management of fly ash, a web- based monitoring system and a fly ash mobile application have been launched by the ministry of power on 3rd Feb. 2018 to provide an interface between producers (TPP's) and potential fly ash users (i.e. cement industry, brick producers). The "ASH TRACK" App will provide information regarding status of power plants within 100 km and 300 kms from a given location, availability of fly ash along with potential users within same area.

These initiatives and policy decisions taken by Govt. of India have led to the progressive utilization of fly ash in diverse fields such as production of Portland Pozzolana cement, development of fly ash based bricks, blocks and tiles, construction of roads, embankments, highways and flyovers, reclamation of low lying areas, back filling and stowing of mines, formation of Roller compacted dams and use in agriculture etc. [6, 8, 20]. The following table-3 shows state wise status of number of thermal power plants installed capacity, fly ash generation-utilization in million tons (MT) and % utilization during the year 2018-19.

Table 3: State wise status of number of thermal power plants (TPP's), installed capacity (MW), fly ash generation-utilization (MT/ %) and Residual ash

Name of the State	No. of TPP's	Installed Capacity (MW)	Fly Ash Generation (MT)	Fly Ash Utilization (MT)	Percentage Utilization (%)	Residual Ash (MT)
Andhra Pradesh	10	13185.00	16.3557	15.9110	97.28	0.4447
Assam	1	750.00	0.4670	0.1410	30.19	0.326
Bihar	5	5240.00	8.0389	3.7176	46.25	4.3213
Chhattisgarh	29	23871.00	33.6561	24.5095	72.82	9.1466
Delhi	2	840.00	0.2940	0.2900	98.64	0.004
Gujrat	12	14742.00	3.2498	3.4376	105.78	-0.1878
Haryana	5	5540.00	5.8995	6.7716	114.78	-0.8721
Jharkhand	7	4897.50	6.3994	6.1448	96.02	0.2546
Karnataka	6	9480.00	4.8656	3.6055	74.10	1.2601
Madhya Pradesh	12	19740.00	23.3303	10.8710	46.60	12.4593
Maharashtra	21	23666.00	23.8370	19.2967	80.95	4.5403
Odisha	10	11323.00	21.5589	17.0270	78.98	4.5319
Punjab	6	6140.00	5.2078	6.8405	131.35	-1.6327
Rajasthan	7	6485.00	5.3645	6.7760	126.31	-1.4115
Tamil Nadu	17	12882.50	10.0573	7.9449	79.00	2.1124
Telangana	7	3782.50	7.0834	5.3601	75.67	1.7233
Uttar Pradesh	20	21370.00	23.0508	14.2799	61.95	8.77081
West Bengal	18	14032.00	18.2340	15.4729	84.86	2.7611
Grand Total	**195**	**197966.50**	**217.0381**	**168.3976**	**77.59**	**48.6405**

Source of data: CEA Report 2018-19 [8]

It is evident from the table 3 that:

- During the year 2018-19 Chhattisgarh state produced highest levels of fly ash of 33.6561 MT) followed by Maharashtra, Madhya Pradesh and Uttar Pradesh with almost similar fly ash generation levels of ~23 million tons.
- Four states namely Andhra Pradesh, Odisha, Tamil Nadu and West Bengal have produced more than 10 million tons of fly ash.
- Ten states namely Assam, Bihar Delhi, Gujrat, Haryana, Jharkhand, Karnataka, Punjab, Rajasthan and Telangana have generated less than 10 million tons of fly ash.
- Assam, Bihar and Madhya Pradesh have shown less

than 50 % utilization levels of fly ash.

- Gujrat, Haryana, Punjab and Rajasthan are the four states that have achieved more than 100 % utilization levels of fly ash.
- Similarly, Jharkhand, Delhi and Andhra Pradesh have acquired more than 95 % utilization levels of fly ash.

Thus, out of 195 thermal power plants 103 TPP's have gained the targets of fly ash utilization as specified by MoEF's notification of 3rd November 2009. It has been made mandatory for all central and state agencies such as central/state Public Work Department (PWD), National Highway Authority of India (NHAI) to encourage use of fly ash-based products in all their projects.

5. STATE GOVERNMENT INITIATIVES

5.1. Rajasthan

To encourage projects based on fly ash in the private sector, the state government has decided that 100 % sales tax and octroi exemption will be provided for a period of 10 years for setting up manufacturing units for bricks, building materials etc. [21].

5.2. Maharashtra

Maharashtra has become the first state to adopt policies of fly ash mission. Government has undertaken a very unique project "Mumbai-Nagpur Super Communication Expressway, also known as Maharashtra Samruddhi Mahamarg" to encourage fly ash- based construction. It is 701 kilometers long with six lanes. It will connect the two capitals of Maharashtra, Nagpur and Mumbai and will save travel time between the two cities by 8 hours. Maharashtra State Road Development Corporation the executing nodal agency also plans to construct 24 townships along the road to provide easy access of skill management centers, healthcare facility, educational institutions, IT parks etc. [22].

Table 3 shows progressive increase in number of power plants, coal consumed, fly ash generation-utilization in India during the year 2015-20 in comparison to 1998-99. The utilization level of fly ash has improved from 11.68 % in 1998-99 to 77.59 % in 2018-19. Following figure 2 displays percentage utilization of fly ash in different sectors during the year 2018-19. Maximum fly ash 26.88 % has been used in cement manufacturing while minimum 0.63 % in agriculture sector [8].

Fig.3 shows fly ash generation and utilization in India in 1998-99 and 2010-20.

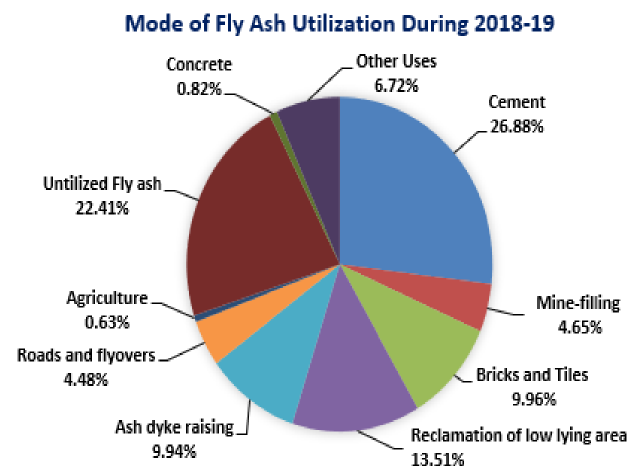

Fig. 2: The pie diagram showing the modes of utilization of fly ash during the year 2018-19. (Source of data: CEA report)

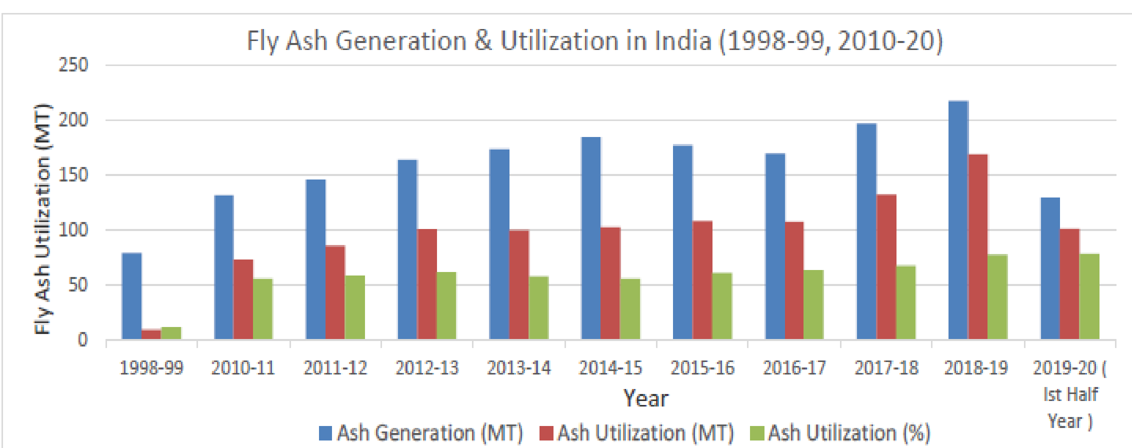

Fig.3: Fly Ash Generation & Utilization in India in 1998-99 and 2010-20. (Source of data: CEA report).

Table 4: Number of thermal power plants, coal consumed, % ash content, flyash generation and utilization (in MT) in India (1998-99 and during 2015-20).

Year	1998-99	2015-16	2016-17	2017-18	2018-19	2019-20 (first half year)
No. of TPP's from which data collected	-	151	155	167	195	194
Coal consumed (MT)	-	536.64	509.5	624.88	667.43	406.91
Average Ash Content (%)	-	32.94	33.22	31.44	32.52	31.73
Fly Ash Generation (MT)	78.99	176.74	169.25	196.44	217.04	129.09
Fly Ash Utilization (MT)	9.23	107.77	107.10	137.87	168.40	100.94
Percentage Utilization	11.68	60.97	63.28	67.13	77.59	78.19

Source: CEA (Central Electricity Authority) Reports 2015-20.

6. FLY ASH UTILIZATION IN INDIA

During the past few decades, the considerable strides taken by Fly Ash Mission, under the ministry of Science and Technology, Government of India has resulted in the progressive utilization of fly ash. The utilization level of fly ash has increased from 9.23 million tons (11.68 %) in 1998-99 to a level of 168.40 million tons (77.59 %) in 2018-19 [8].The intrinsic worth of fly ash for applications in diverse areas has been acknowledged and is now being treated as a beneficial commodity rather than an industrial waste. Few common modes of fly ash applications that are currently followed in India and various new domains for eco-friendly and economic utilization of fly ash have been discussed below.

6.1. Application of Fly Ash in Cement Industry

Construction industry is one such area which has an enormous potential to incorporate fly ash. Studies confirm that 1 ton of CO_2 is liberated in environment during production of 1-ton Portland cement, which is the most widely used cement worldwide. Replacement of Portland cement with fly ash leads to net reduction in energy use and greenhouse gas emissions, to the extent of its proportion replaced in cement [16]. This addition also extends technical benefits of concrete, reduces its cost, saves virgin raw materials (coal, limestone etc.) and precious land resources required for fly ash disposal [10,12]. On the other hand, it serves for an efficient method for safe disposal and sustainable utilization of fly ash [13].

6.1.1. Portland Pozzolana Cement (PPC)

By virtue of its pozzolanic reactivity the fly ash, generally in the range 15-30 %, is used as a replacement for Portland cement [23].The replacement levels of fly ash (class- F mainly) as high as 70 % of the total cement material, have been achieved in the construction of Roller Compacted Dams (RCC) such as Ghatghar Dam Project, Maharashtra, India [6].This addition not only saves cement cost but also contributes to the enhanced strength and durability of the concrete.

6.1.2. Fly Ash Based Geopolymer Concrete

Fly ash based geopolymers have emerged as a promising new cement substitutes to conventional concrete in the field of building materials. Class- F or low calcium fly ashes being the source of aluminum-silicate material act as a cementing material in presence of alkali [24].

6.1.3. Asphalt concrete

It is a composite material comprised of an asphalt binder, aggregates and fly ash as mineral filler. The hydrophobic nature of fly ash provides pavements better resistance to stripping, improves stiffness of asphalt matrix, enhances durability and rutting resistance [25]. Incorporation of fly ash into concrete offers following benefits [24, 26]:

- The ball bearing effect of fly ash particles exert a lubricating action, reduces water demand of wet mix and enhances workability of wet mix.
- Improves water resistance by forming calcium silicate hydrate (C-S-H) gel due to its pozzolanic activity.
- Improves resistance towards weak acids, salts and sulphates.
- Contributes long term compressive strength to the concrete.
- Provides better resistance to chloride ion penetration.
- Reduces bleeding of concrete,
- Provides excellent protection to the reinforcing steel against corrosion.
- Enhances durability against freeze-thaw.

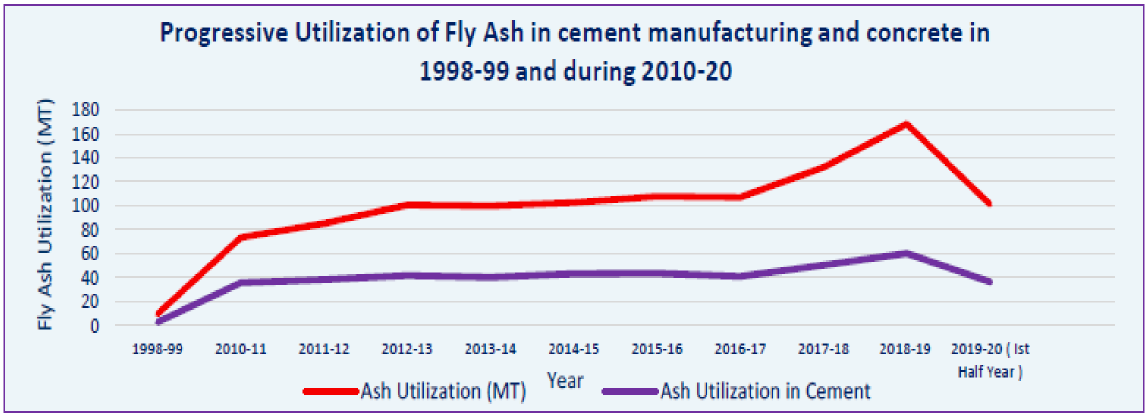

Fig. 4: Progressive fly ash utilization in cement-concrete in 1998-99 and during 2010-20.

It is evident from above figure that fly ash utilization in-cement industry was 2.45 million tons in 1998-99 which has gradually increased up to 60.11 million tons in 2018-19 and million tons in 2019-20 (1^{st} Half Year) [8, 27].

6.2. Application of Fly Ash in Building Materials

The utilization level of fly ash in bricks, blocks, tiles have improved from 0.70 MT in 1998-99 to 21.61 MT in 2018-19 and 10.18 MT in 2019-20 (first half year) [8, 27].

6.2.1. Fly ash bricks

The dual purpose of top soil conservation and constructive utilization of fly ash is served by fly ash bricks, as they do not require clay for their manufacture.

6.2.2. Fly ash -Clay fired bricks

These bricks are prepared by firing a mixture of clay and fly ash where unburnt carbon of the fly ash serves as a fuel for firing [6,13].

6.2.3. Fly ash -Lime-Gypsum bricks

An eco-friendly technology, mostly popular in Andhra Pradesh & Odishafor the manufacture of FAL-G bricks has been invented by the Institute of Solid Waste Research and Ecological Balance, Visakhapatnam[28]. These bricks are light weight and cheaper than fly ash lime/fly ash-clay bricks, sets and harden in presence of moisture and gets strength with age. These do not require sintering in contrast to clay bricks which incorporates coal burning and CO_2 liberation. Due to low water absorption (4-12 %only) plastering is optional. These may be used for specific applications like canal lining, dam construction and water tanks and have a vast potential for applications in cyclone devasted areas of the state.

6.2.4. Cellular light weight concrete blocks

These are prepared with fly ash (1/3 or 1/4 of the total material constitution), sand, water and foam, manufactured from biodegradable foaming agent. These blocks display better acoustics, better thermal insulation, better strength to weight ratio than conventional concrete blocks. The use of fly ash results in saving of steel, mortar and cement costs [29].

6.3. Fly Ash in Construction of Roads, Embankments, Flyovers & raising of Ash Dykes:

high-volume application of fly ash includes construction of roads, paving's, building embankments, flyovers and ash dykes raising which save the top fertile soil and reduces low lying areas. Fly ash in road construction is employed for following purposes-

- Stabilization and Fabrication of sub base and base.
- Upper layers of pavements.
- For filling purposes.

Studies confirm that an increase of 84.6 % in California Bearing Ratio (CBR) could be achieved by addition of only fly ash to soil which is an essential factor for such applications[7]. Other important parameters include grain size distribution, compressibility, permeability and frost susceptibility. Owing to large uniformity coefficient of clay sized particles, fly ash provides better compaction than soil [30, 31]. The use of fly ash in the construction of Nizamuddin bridge road embankment (about 2 kms long and of 8 meters height) at Delhi, India in a flood zone demonstrates utilization of fly ash in adverse conditions. The use of fly ash saved Rs. 1.4 crores in a total project of Rs.10 crores [10]. The utilization of fly ash for above applications was 1.055 million tons in 1998-99 which effectively increased to 9.72 million tons during the year 2018-19 and 21.60 MT in 2019-20 (1st half year)[8, 27].

6.4. Application of Fly Ash in Agriculture

Another important sector where large volume of fly ash could be used is agriculture, forestry and horticulture. By altering physio-chemical parameters, nutritional status and pH of soil, addition of fly ash exerts beneficial impact on soil health and plant productivity. The effect of natural radio activity and heavy metal content of fly ash has been found to be in safe limits when used in optimum quantity [32]. Fly ash utilization during 1998-99 was 0.13 MT which has increased to 1.38 MT in 2018-19 and 0.42 MT in 2019-20 (first half year) [8, 27]. Following effects on plants have been reported by the incorporation of fly ash-

- Fly ash act as an excellent soil ameliorating agent in forestry, agriculture and waste land reclamation). It improves soil texture and fertility by increasing porosity, water holding capacity and reducing bulk density of soil. Use of fly ash in place of lime as “soil conditioner” has a potential to cause a reduction in net CO_2 emission and decrease in global warming. Fly ash is used as a buffer to neutralize acidic soils due to their alkaline nature (pH 4.5-12). Reduces growth of pathogenic microorganisms of soil while favors the growth of nitrogen fixing bacteria and phosphorus solubilizing bacteria. Act as pesticide [19].
- The amount of chemical fertilizers in agriculture could be reduced by the use of fly ash along with chemical fertilizers / organic materials (i.e. sewage sludge, cow dung)/micro-organisms in an integrated manner thereby reducing environmental pollution [33].

Fly ash is a potential reservoir of all micro and macro nutrients essential for healthy plant growth except for nitrogen and carbon. Hence, it promotes plant growth by accelerating vital nutrient uptake. It has been reported that fly ash increases the yield of cereals, oil seeds, pulses, cotton and sugarcane by 10-15 %, vegetables by about 20-25 % and root vegetables by 30-40 %. [34].

6.5. Use of Fly Ash in Back filling of Mines

Fly ash is being widely used for back filling of open cast mines and underground mines which leads to saving of precious fertile top soil and river sand significantly [35]. About 0.65 million tons of fly ash was used during the year 1998-99 for back filling of open cast and underground mines which has significantly increased up to 10.10 million tons in 2018-19 and 5.97 million tons in 2019-20 (first half year) [8, 27].

6.6. Use of Fly Ash in Reclamation of Low-lying Areas

One of the important high-volume application of fly ash is in reclamation of low-lying areas which contributes in saving of fertile top soil and prevention of water logging [36].The utilization of fly ash for reclamation of low-lying areas was 4.17 million tons in 1998-99 which has shown substantial increase of 29.32 million tons during the year 2018-19 and 18.69 MT in 2019-20 (first half year) [8, 27].

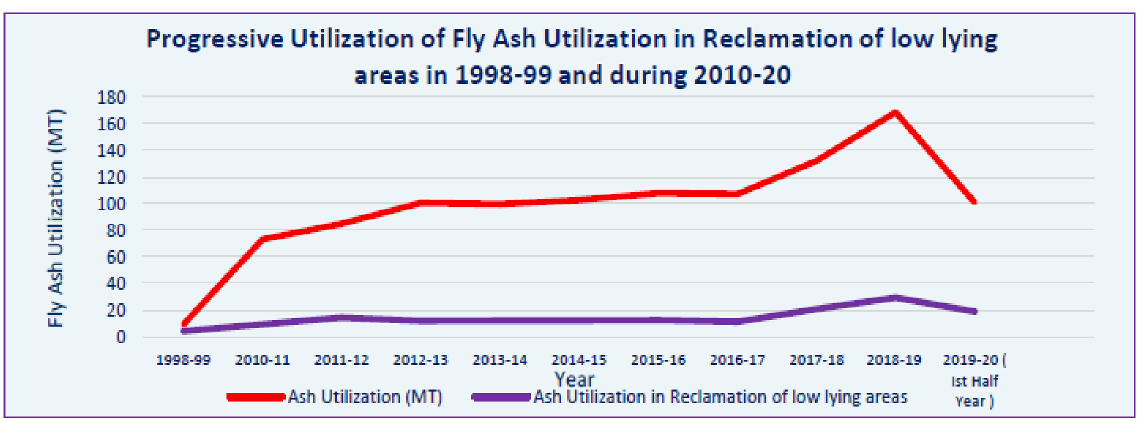

Fig. 5: Fly Ash Utilization in Reclamation of Low-lying area during 1998-99 & 2010-20.

7. OTHER DIVERSE APPLICATIONS OF FLY ASH

Apart from conventional use of fly ash as a building material, some new domains have been explored worldwide for its economic and eco-friendly utilization. These are discussed below.

7.1. Fly Ash as a Source of Valuable Materials

7.1.1. Recovery of Metals

Coal fly ash is a reservoir of various metals and minerals which have huge demand in industries while their natural sources are depleting. Hence recovery of these potential resources from fly ash provides an alternative method to save mineral resources and resolves the problem of ash disposal at the same time [37]. In a study four metals namely copper, zinc cadmium and lead were extracted from municipal solid waste fly ashes by thermal and chlorination treatments [38]. Similarly, extraction of zinc, chromium and nickel via alkaline-acid leaching and alumina by low temperature calcination of bisulfite has been reported [39, 40].

7.1.2. Recovery of Cenospheres

Aluminum silicate microspheres recovered from fly ash are finding increasing applications in the polymer industry and in manufacture of rubber products. Their reinforcing property has been exploited to achieve hardness, stiffness and to enhance abrasion resistance [41].

7.1.3. Recovery of Rare Earth Metals

Extraction of rare earth metals from coal fly ash is more economic and saves 75% energy in comparison to mining of minerals. According to a study if rare earth elements are extracted from coal ash, 10-15 % of currently available fly ash would be sufficient to meet the rare elements demand in the United States. These are widely used in the manufacturing of hybrid car batteries, permanent magnet motors for wind turbines, disk drives, automobile catalytic converters and as catalysts in industries [42].

7.1.4. Recovery of unburned carbon

Attempts have been made by researchers for recovery of unburned carbon from coal fly ashes. The unburned carbon is extensively used in the production of synthetic graphite for electrodes and lubricants, carbon-carbon composites in the aviation and space sciences, in printing industry and in water /gas purification [43].

7.2. Fly ash-based ceramics

The physio-chemical parameters of fly ash exhibit resemblance with volcanic ash, natural soil etc. due to the abundance of silica, alumina and iron and hence is a suitable material for ceramic applications. The ceramics incorporating fly ash have been developed by the National Metallurgical Laboratory, Jamshedpur, with good abrasion resistance [14, 44].

7.3. Fly ash-based polymers as wood substitutes

These are used as wood substitutes and are prepared by using fly ash as the matrix and jute cloth as the reinforcement. The fly ash-based polymers are stronger, more durable, resistant to corrosion and cost effective than wood. The Regional Research Laboratory Bhopal, in collaboration with Building Materials and Technology Promotion Council (B.M.T.P.C) has developed this technology. The polymer products find applications as door shutters, partition panels, flooring tiles, wall paneling and ceiling [45].

7.4. Fly ash-based distempers

As a replacement of white cement, fly ash-based distempers have been used in many buildings of Neyveli, Tamilnadu with satisfactory performance [13].

7.5. Fly ash as fillers

A fly ash-epoxy (thermo setting resin) composite was fabricated by the addition of fly ash as filler. Incorporation of fly ash with smaller particle size reduced the weight of composite and enhanced its mechanical strength. Due to high specific strength, epoxy resins find wide applications in air crafts, electric components, automobiles and sports equipment [46].

7.6. Application of Fly Ash in Pollution Control

7.6.1. Removal of Air and Water Pollutants

Air pollutants such as nitrogen oxides (NO_X), Sulfur dioxide (SO_2), volatile organic compounds (VOC's) and water pollutants (i.e. heavy metals, phosphorus, boron, fluorides, dyes, phenolic compounds) cause detrimental impacts on human health and environment. Due to high porosity, large specific surface area fly ash was used to fabricate a low cost and high adsorption efficiency nano fiber membrane adsorbent for removal of pollutants. Thus, utilization of nano fiber technology has enormous potential to mitigate environmental pollution in the future [47].

7.6.2. Removal of CO_2

The potential of fly ash-based adsorbents has been successfully explored for capture, storage and utilization of CO_2. It offers use of fly ash in diverse ways such as a capture material, as a medium for sequestration of carbon dioxide via mineralization, as a catalyst or as a catalyst support for CO_2 utilization processes [48].

7.6.3. Removal of oil spills from sea water

Oil spills are threat to marine eco-system. In a study fly ash was organically modified by using the cationic surfactant and was successfully employed for oil removal from sea water [49].

7.6.4. Waste stabilization and its recycling

Stabilization/Solidification of municipal waste incineration incorporating fly ash, is a widely adopted method worldwide for immobilization of heavy metals. Due to the use of Portland cement as a binder, product obtained had a potential to be utilized as filler, an effective material for back filling and in embankment constructions [50].

7.6.5. Removal of toxic metals by fly ash zeolite adsorbent

A new approach for fly ash application is the synthesis of zeolites. Zeolites are described as alkali activated aluminosilicate mineral binders comprising of a polymeric Si-O-Al framework. These are widely used as molecular sieves, catalysts, adsorbents and in ion exchange. Fly ash admixed X-type zeolite was synthesized via alkali fusion followed by hydro thermal treatment. It was used efficiently as an adsorbent for removal of toxic heavy metals (Fe, Zn, Pb, Cu, Cd) from effluents from various mineral and metal processing industries [51].

7.6.6. Removal of dyes from textile mill effluent

A fly ash based nano composite was prepared by systematic biopolymer transformation of fly ash cenospheres and was used for removal of dyes (DO & DB) from textile mill effluents. This adsorbent was eco-friendly, more economic and exhibited two times better efficiency than most extensively used activated carbon adsorbents. Moreover, used adsorbent could easily be recycled in brick making to minimize environmental pollution [52].

7.6.7. Removal of fluoride from ground water

Fly ash has been successfully employed for the removal of fluoride from ground water via adsorption using coal fly ash [53].

8. CONCLUSION

The "Fly Ash Mission", Government of India has left no stone unturned to maximize gainful utilization of fly ash through the implementation of various policies and decision making, by strict monitoring of fly ash disposal and extensive research work and development. Its concrete efforts have encouraged the economic and eco-friendly utilization of fly ash in diverse applications such as construction of roads, dams, buildings fly overs etc., back filling of mines, agriculture. Some areas such as cement industry, agriculture, reclamation of low-lying areas have a potential for vast amount of fly ash incorporation. Technologies involved in new domains like metal recovery, removal of pollution and waste stabilization by fly ash are in infancy stage. Their large-scale adoption at commercial level is imperative for further development. The economic viability and evaluation of environmental impact of all such methods should also be considered simultaneously. Although a lot of attempts have been made but this is just a tip of an iceberg. A huge amount of fly ash is still dumped unutilized in ash ponds and more rigorous efforts are required to achieve targets of 100 % fly ash utilization.

9. REFERENCES

1. Coal in India 2019, report by Australian Government, Department of Industry, Innovation and Science. (www.industry.gov.au>sites>default > files>2019-08e)
2. Energy Statistics-2019, (26 th issue), Central Statistics Office, Ministry of Statistics and Program implementation, Govt. of India, New Delhi. (http: //www.mospi.gov.in)
3. Indian Minerals Yearbook 2018 (part-III: Mineral Reviews), 57 th Ed. Coal and Lignite, Govt. of India, Ministry of Mines.
4. BP Statistical Review of World Energy 2020 Report-69 th edition.
5. Coal.nic.in/content/production-and-supplies
6. Singh Y, Archives-Fly Ash Utilization in India 2020. Wealthy Waste. Com
7. Alam J and Akhtar MN. *International Journal of Emerging Trends in Engineering and Development*, 2011; **1 (1):**1-15.
8. Central Electricity Authority Report on Fly Ash Generation at Coal /Lignite Based Thermal Power Stations and its Utilization in the Country for the Year 2018-19.

9. Upadhyay A and Kamal M, 2007; Thesis submitted to Department of Mining Engineering, NIT Rourkela, Orissa.
10. Singh Y, Archives-Fly Ash Utilization in India 2017. Wealthy Waste. Com
11. Coal Ash in India, A Compendium of Disasters, Environmental and Health Risks, July 2020 Report.
12. Ghosh KG, Mukherjee K, Saha S. *International Journal of Geology, Earth and Environmental Sciences*, 2015; **5(2)**:74-91.
13. Nawaz. *Inernational Journal of Innovative Research in Science, Engineering and Technology,* 2013; **2(10):**5259-5266.
14. Tiwari MK, Bajpai S, Dewangan UK. *Int Res J Engg & Technol*, 2016; **3(4):**949-956.
15. Dhadse S, Kumari P, Bhagia LJ, *Journal of Scientific and Industrial Research*, 2008; **67**:11-18.
16. Kaur A. Ph D Thesis, 2016, Submitted to Department of Civil Engineering, IIT, Delhi.
17. Khan I, Umar R, *Ground water for Sustainable Development*, 2019; **8:**346-357.
18. ASTMC618, Annual book of American Society of Testing and Material Specification Standards volume: 4.02, West Conshohocken, Pennsylvania, 1994.
19. Kishor P, Ghosh A, Kumar D. *Asian Journal of Agricultural Research*, 2010; **4:**1-14.
20. Report on Implementation of Action Plan to Achieve 100 % Fly Ash Utilization by the Thermal Power Plants by MoEF& CC, CPCB, IIT Roorkee-O.A. No. 117, 102 &499 of 2014. https://greentribunal.gov.in/sites/default/files/alldocuments/report
21. dcmsme.gov.in > policies > state >rajasthan
22. https://indiancementreview.com/feature/fly-ash-utilization-in-samruddhi-mahamarg/116005.
23. Celik O, Damci E, Piskin S, *Indian Journal of Engineering and Materials Sciences*, 2008; **15**:433-440.
24. Wattimena OK, Antoni,Hardjito D, AIP Conference Proceedings 1887, 020041 (2017).
25. Likitlersuang S, Chompoorat T. *International Journal of Pavement Research and Technology,* 2016; **9(5):**337-344.
26. Bremseth S K, COIN Project Report 18, 2010.
27. Report on Fly Ash Generation at Coal /Lignite Based Thermal Power Stations and its Utilization in the Country for the First Half Year (April 2019-September 2019) CEA 2019-20.
28. Project Profile on Fly Ash Building Products. http://www.msmedikolkata.gov.in>flyashbuilding bricks.
29. Hemavathi S, Karnan D. *International Research Journal of Engineering and Technology,* 2020; **7(6):**5912-5919.
30. Trivedi JS, Nair S, Iyyunni C. *Procedia Engineering,* 2013; **51**: 250-258.
31. Kumar V, Mathur M, Sinha SS. Fly Ash India 2005; Fly Ash Utilization Programme (FAUP), TIFAC, DST, New Delhi-110016.
32. Basu M, Pande M, Bhadoria PBS, Mahapatra SC. *Progress in Natural Science*, 2009; **19**:1173-1186.
33. Dahiya H, BudaniaYKr, *Int. J. Curr. Microbiol. App. Sci.,* 2018; **7(10):**397-409.
34. Malik A, Thapliyal A, *Critical Reviews in Environmental Science and Technology*, 2009; **39**:333-366.
35. environmentalclearance.nic.in>public-display> circulars
36. ospcboard.org>wp-content>uploads/2017/01/ Guidelines-for-Reclamation-of-Low-Lying-Areas
37. Sahoo PK, Kim K, Powell MA, Equeenuddin SK Md. *Int J Coal Sci Technol,*2016; **3(3):**267-283.
38. Kubonova L, Langova S, Nowa B, Winter F. *Waste Management,*2013; **33**:2322-2327.
39. Liu J, Chen J, Huang L. *Sci Rep*, 2015; **5**. https://doi.org/10.1038/srep17270.
40. Guo C, Zou J, Ma J, Yang J, Wang. *Minerals*, 2019; **9**:585-599.
41. Zyrkowski M, Neto RC, Santos LF, Witkowski K.*Fuel,* 2016; **174**:49-53.
42. Recovery of Rare Earth Elements and Compounds from Coal Ash. US Patent: US8968688B2.
43. Badenhorst CJ, Wagner NJ, Valentim BRV, Viljoen KS, Santos AS, Guedes A. *Coal Combustion and Gasification Products*, 2019; **11**:89-96.
44. Sharma G, Mehla SK, Bhatnagar T, Bajaj A, *International Journal of Modern Physics: Conference Series*, 2013; **22:**99-102.
45. Saxena M, Prabhakar. “Emerging Technologies for Third Millennium on Wood Substitute and Paint from Coal Ash” Second International Conference on Fly Ash Disposal and Utilization, New Delhi, February 2000.
46. SimJ, Kang Y, kim B J, Park YH, Leo YC. *Polymers*, 2020; **12**:79-91.
47. GeJ C, Yoon, S Ki, Choi NJ. *Appl. Sci.*, 2018; **8**:1116-1140.
48. Dindi A, Quang DV, Vega LF, Nashef E, Abu-Zahra Md R, *Journal of CO_2 Utilization*, 2019; **29**:82-102.

49. Banerjee S, Joshi MV, Jayaram RV, *Desalination,* 2006; **195(1):**32-39.
50. Tang Q, Liu Y,Zhou T.*Advances in Materials, Science and Engineering*, 2016; https://doi.org/10.1155/2016/7101243.
51. Solanki P, Gupta V, Kulshrestha R. *E-Journal of Chemistry*, 2010; **7(4):**1200-1205.
52. Markandeya Shukla, SP, Mohan D. *Innovation in Global Green Technologies*, 2020; DOI: 10.5772/intechopen.88984.
53. Chakraborty GM, Das S Kr, Mandal SN, International Conference on Pure and Applied Chemistry, 2016; *Emerging Trends in Chemical Sciences,* pp 69-87.