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A Critical Examination of the Potential Applications of Flyash in Several Industries: Especially the Use of Flyash in Agriculture Sector

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Abstract: ***Disposing of solid waste produced through various sources is an emerging problem worldwide. Flyash, a form of solid waste from thermal power plants, involves a massive amount of water, energy, and land area ash ponds for disposal. This industrial waste removal has raised an increased energy demand along with various environmental, economic, and social problems, and it is rising globally. Its production from the coal - based thermal power plant is about 160 million tons annually which is expected to rise to 600 million tons by 2030, according to the current ENVIS CSIR report. It is an alarming situation that demands an avid generation of strategies for properly managing fly ash. Recent research has shown that this waste can be salvaged as a potential resource material in agriculture. A comprehensive review of numerous studies has been reported in this study, which systematically covers the importance, scope, and apprehensions regarding flyash utilization in different sectors. Further, some studies also report some established solutions to handle the problems of radioactivity and heavy metal content in flyash, but still, long - term confirmatory research and demonstration are necessary. This review also identified the helpful utilization of flyash in agriculture. The countries like India monitoring soil health, crop quality is a significant concern for farmers. Agricultural lime application contributes to global warming as the Intergovernmental Panel on Climate Change (IPCC) assumes that all the carbon in agricultural lime is finally released as CO_2 to the atmosphere. It is expected that using flyash instead of lime in agriculture can reduce net CO_2 emissions and will reduce global warming too. Hence, the importance of flyash of crop health monitoring is highlighted.***

Keywords: Flyash management, coal - based thermal power plant, crop quality, CO_2 emission, climate change.

1. Introduction

Flyash is the end product obtained from ignited pulverized bituminous or sub - bituminous coal (lignite) in the furnace of thermal power plants remaining with remnants of partially burnt coal. It constitutes trace elements that vary in their concentration depending upon the point of collection in the combustion process, wherein fly ash hasa higher concentration of volatile trace elements such as cadmium, chromium, lead, nickel, zinc, copper, vanadium, mercury, arsenic, and selenium as compared to the bottom ash [1, 2]. The coal ash byproduct has been classified as a Green List waste [3].

The utilization of flyash help in increasing the goal of sustainable development from small to large scale worldwide to utilize such a valuable solid waste in different sector and overcome the use of natural materials [4 - 8]. The disposal of this byproduct of energy, acquired from (30 - 50%) bituminous or sub - bituminous coal from thermal power stations, in addition to various captive power plants, is generated in large quantities each year and so faces indiscriminate disposal, which is a significant worry. According to the current ENVIS CSIR study, its production as a byproduct from coal - based thermal power plants (TPPs) is approximately 160 million tons (MT) per year and is predicted to increase to approximately 600 MT by 2030. Ash ponds absorb a large quantity of water, energy, and land area when a large amount of flyash is removed from thermal power plants [9]. Even though byproducts from the thermal industry are not considered waste under the Basel Convention [10], many countries disregard them as waste despite recycling their use.

According to the American Coal Ash Association report, agriculture, wasteland reclamation, and civil engineering use 32% of the flyash, 30% of the bottom ash, 94% of the boiler slag, and 9% of flue gas desulfurization sludge [11]. Still, many countries like Denmark, Netherlands, and Italy are prosperous in using 100% of flyash while France, Germany, and Australia (85%) followed by Canada (75%), USA (65%), UK (50%), China (45%) and India (38%). Besides their use in construction, many countries utilize the results of various studies to evaluate its efficacy as an amendment in the agriculture sector. Low flyash utilization in India is the unavailability of appropriate cost - effective technologies. The flyash utilization in different construction sectors studied in past studies disclosed the most effective solid waste in the construction sector, such as cement, concrete, bricks, tiles, etc., reported by [12 - 18].

This paper aims to highlight the utilization of flyash as a value - added product in different sectors and open new avenues with a strong base of its efficacy in improving productivity and thus minimizing the environmental impact on its disposal.

2. Methodology

The systematic literature review (SLR) method was used for this review article. The SLR approach for the current review article is a defined list of published articles from the author's works. The technique reveals the research of those working in the same field for several years. The search approach is aimed at databases such as Google Scholar, Scopus, Web of Science, and online search. The essential words are flyash,

flyash - based bricks and blocks, flyash - based cement and concrete, and flyash utilization in agriculture.

The study focuses on mapping previously available information on flyash utilization in various sectors and waste management. The search then narrowed to flyash, flyash - based bricks and blocks, flyash - based cement and concrete, and flyash utilization in agriculture. Articles from other irrelevant sources were eliminated. At this point, 116 articles have been discarded.

A total of 56 papers were picked for the data extraction phase. The selected articles come from case studies, peer - reviewed research articles, peer - reviewed review articles, conference papers, and reports from registered organizations. Fig.1 shows the data for systematic inclusion and exclusion for this review study.

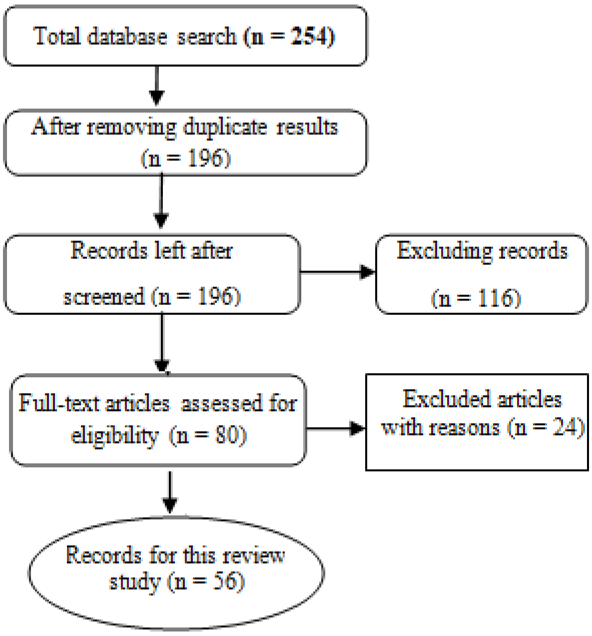

Figure 1: Literature's systematic inclusion and exclusion framework

3. Replacement of Flyash in Different Sector

The global Fly Ash Market was valued at USD 4.13 Billion in 2018, expected to rise to USD 6.86 Billion by 2026, at a CAGR of 6.6%. Its market is driven by the growth of the construction industry, increasing infrastructure, road development, rules and regulations for handling fly ash and increasing focus on using environment - friendly products. Overall, infrastructure development plays a vital role in its market growth. On a parallel side world population is registered to grow 1.07% annually in 2018 - 2019. Such an increase in population hikes the demand for electricity generated from industrial plants, where coal - power plants play a significant role, contributing 40% of worldwide electricity production. And thus, fly - ash production as a byproduct of coal - fired electric power plants will also increase, produced as a dust particle during electricity generation from coal. It alone accounts for 70% of total waste produced during coal combustion. Thus, to sustain electric power generation through coal combustion, the reuse of its byproduct is necessary. Otherwise, it will demand a considerable landfill and energy consumption to dispose of; otherwise, it will be hazardous. It can be utilized in many sectors such as Portland cement, ricks manufacturing, soil stabilization material, as a component in geopolymers, roller compacted concrete dams, etc. Specifically, the significant escalation of global construction has generated demand for building material like cement, concrete, bricks, iron steel, etc [19 - 22].

3.1 Flyash - based ordinary Portland cement

Ordinary Portland cement (OPC) is one of the most attractive sectors of utilization flyash in production. Up to 20 - 35%, flyash can directly besubstituted for cement as a blending material. Adding flyash to cement significantlyimproves thequality & durability characteristics of the resulting concrete. Further, the flyash can be replaced by OPC in concrete and mortar production. In India, current cement production per annumis comparable tothe production of flyash. Hence, even without enhancing cement's production capacity, the cement's availability (fly ash - based PPC) can be significantly increased [23 - 27].

3.2 Flyash - based concrete

The flyash based concrete is popular in developed countries, it accounts for less than 5% of total cement consumption in India. Its popularity has only recently begun to develop rapidly. In the country, an average of 20% flyash (of cementitious material) is used, which can quickly rise to very high levels. Various ingredients and quality parameters are strictly maintained/controlled in ready - mix concrete, which is impossible in on - site concrete. Thus it can accommodate a greater quantity of flyash. The incorporation of flyash also affected high temperatures, chemical attacks, and void ratio and effectively increased concrete density. The use of flyash is also effective in bacterial self - healing concrete production [28 - 34].

3.3 Flyash bricks and blocks

Flyash can be utilized at a percentage of 40 - 70%. Other elements include lime, gypsum/cement, sand, stone dust/chips, etc. Minimum compressive strength (28 days) of 70 kg/cm^2 is readily achievable, and this can be increased to 250 kg/cm^2 (in autoclaved form). The bricks and blocks prepared in different percentages of flyash and other solid waste, such as recycled fine aggregate, silica fume, and crumb rubber, produced cost - effective high - strength bricks and blocked satisfied all standard requirements reported in the published studies [13, 17, 21, 35 - 39].

3.4 Flyash in road construction

Fly ash can be used to build roads and dams. This approach has numerous advantages over traditional procedures. Saves topsoil that would otherwise be used and avoids forming low - lying areas (by excavating soil for embankment building). It avoids repeated costs for excavating soil from one location for building and filling in low - lying locations developed. Flyash is also used in design mix pavement to improve the stability and flow of the asphalt mix design [40]

3.5Utilization of flyash in agriculture

3.5.1Effects of flyash on soil pH

Effective crop production needs an optimum pH range from 6.5–7.5. At the same time, soil fertility gets impaired at a pH lower than 5.5; it allows the solubility of toxic elements, which delays root growth like manganese and aluminum. In such instances, adding organic matter to the soil buffers plants against acidity and helps in production with lower pH. The pH of FA varies to a higher range from 4.5 to 12.0; it can be acidic or alkaline depending upon the parent coal. Depending upon their content, viz. Silica, Alumina, and Iron Oxide can be classified into two types of Fly ash: Class F (Low Lime) and Class C (High Lime), which reflects their acidic or alkaline nature. Acidity increases with S content, while fly ash with lignite has high Ca and is alkaline. Various studies done so far provide mixed results on changes in soil pH; it can be attributed to the fact that it mainly depends upon the parent coal, which will affect the chemical composition of fly ash. Thus acidity or alkalinity can be altered in the soil as per the crop demand [41 - 43].

An increased pH from 5.38 to 6.01 has been observed in post - harvest soil by adding flyash; hydroxide and carbonate salts convey this fly ash property to neutralize the soil acidity [50]. Other chemical reactions like the production of Hydroxyl and another ionic form by the reaction of Calcium Oxide present in the fly ash with water in the presence of CO_2 and Na presence also elevate the pH. A similar study reports increased pH in mine soil after fly ash amendments. Some studies report the same pH in post - harvest soil even after adding fly ash; it can be due to the non - characterization of the flyash added and the soil type. Reduction in soil pH from 10.0 to 8.5 was also observed, along with a significant decrease in electrical conductivity after fly - ash application. Thus an amalgam amelioration of soil pH by fly ash has vast results in different types of soils, including marginalized lands, mine spoils for agriculture, and forestry [44 - 47].

3.5.2 Effects of flyash on cation exchange capacity of soil

The chemical diversity of fly ash has a different effect on soil CEC, a strict behavior of soil characteristics that cannot be altered. Though the results obtained after fly ash application do not cause a fruitful change, as it decreases the CEC, to avoid nutrient leaching, CEC should be increased. It was found to be decreased with the addition of fly ash in expansive soils; similar findings were observed on sandy clay (SC) and low plasticity clay (CL), and its decrease in CEC was significantly different from the lime application. Found that Karrakatta sands in India had lower CEC than fly ash. Upon applying flyash, it was expected that there be an increase in the CEC of the soil and an increase in nutrient retention as cationic plant nutrients. Much research is needed to confirm and establish the Effect of CEC on different soil types. [48, 49].

3.5.3 Effects of flyash on water holding capacity of soil

Fly ash particles are silt - sized in nature, a distinctive feature that allows them to alter the soil silt content. Thus the WHC of the soil generally increases after fly ash application. Micro - porosity increased from 43% to 53%, while water - holding capacity increased from 39% to 55% after adding flyash to soils. It was also confirmed with the gradual addition of fly - ash concentration from 0, 10, 20, and 100 % v/v in the soil; it increased porosity and water - holding capacity. It was also tested on sandy soil; similar growth was found on porosity and WHC. It was also analyzed that this effect varies with the particle size of fly ash obtained from different thermal plants; fly ash with bigger particle size has higher WHC. A study also shows that this improvement in WHC is beneficial in crop production under rain - fed soil. So flyash can lengthen the growing season of land areas where the season is short with poorly distributed rainfall. A significant increase in soil moisture content was also observed after fly - ash application in situ in the top 10 cm; simultaneously, it reduced the infiltration rate due to its high slit content. So, to avoid water logging conditions in the field, applying fly ash at an optimum rate is suggested. All such studies affirm the beneficial effect of fly ash application and the increase in WHC of different types of soil; still, its use is limited in many countries struggling with significant marginalized lands; it can help them improve their productivity. [7, 10, 47, 50].

3.5.4 Effect of flyash on crop productivity

Various studies discussed now have shown the excellentEffect of Fly ash on the physical and chemical characteristics of soil, altering its pH, increasing WHC, and porosity, reducing bulk density, increasing root penetration, etc. It is also proved to be a potential soil conditioner, which helps increase the solubility and availability of plant nutrients; thus, overall, it helps enhance crop productivity in low - fertility acid lateritic soils. Studies have proved its overall impact on the crop, the yield of the rice crop and its growth was improved by the amendment of 40% flyash in soil, but when its application rates were raised from 60% to 100 %, it caused a gradual decline in productivity. This adverse effect can be attributed to the saturation reached due to the chemicals like sulfate, chloride, carbonate, and bicarbonate present in fly ash at higher levels in added ratio. A similar threshold level of fly ash application in rice crops was observed with seven different soils of varying texture after a gradual increase in supplication of fly ash mixture at 0, 2, 4 and 8 % (w/w) levels; wherein moderate rates of 2 and 4 % (w/w) were found to increase the yield of dry rice matter while at 8 % (w/w) it caused significantly depressed growth. [10, 50, 51].

Its effect on soil nutrients is not uniform; it causes an increase in N, S, Ca, Na, and Fe and a significant decrease in P and Zn in rice grains. A significant increase was observed after mixing 75 % of an inorganic fertilizer GRD (100: 60: 40) + 20 t/ha flyash and 5 t FYM in soil, in various parameters for growth, viz. high total tillers, effective tillers, panicle length, and number of grains per panicle of rice. Similar treatment caused a significantly higher paddy and straw yield with 40 and 60 t/ha flyash. Application rates of 5, 10, and 20 t/ha fly ash combined with nitrogen rates of 25, 50, 100 kg/ha significantly increased wheat grain and biomass yield. It was found that sorghum growth characteristics were influenced significantly in a treatment combination of 40 kg N/ ha and 20 t/ha fly ash, causing the Harvest index of sorghum to be increased from 21.6 to 29 %; while yield increased from 1.49 t/ha to 1.56 t/ha; It was observed that this combination caused a synergistic effect as the highest yield of sorghum 1.87 t/ha was obtained. Maize and soyabean growth were also enhanced specifically after the foliar application of fly ash, increasing their photosynthetic pigments. It was also reported in tomato crops, which was significantly increased to 81% after 40% fly ash application; further, it also caused higher tolerance to wilt fungus (Fusarium exosporium) in tomato crops, thereby increasing the yield [44, 51 - 54].

3.5.5 Impact of flyash on arenosols

Arenosols refer to sandy soils lacking substantial soil productivity. Such soil occurs over large areas in Africa, central and Western Australia, the Middle East, and central China, and some areas around the coastlines worldwide. They are poorly aggregated, highly leached, and acidic, which plays a dual role in distressing crop productivity; unavailability of macro - nutrients and increased toxicity of many micro - nutrients present in arenosols make nutrient or water management a more significant challenge. Micro and macro elements concentrated in the flyash during combustion can be a potential resource to provide these nutrients in such sandy textured soils. Under these essential elements, flyash can modify the physical properties of soils where it works as a soil conditioner, enhancing the yield of the crops. Strategies to enhance the soil fertility and water holding capacity in Arenosols remain a significant constraint to improving crop yield in countries such as Zimbabwe. Though adding organic manure can improve the aggregation of the primary particles in such soils, it still increases the economic burden on the ordinary farmer working in the field. To reduce this economic load and reuse the waste product of the coal industry, flyash can be used as a safe and sustainable source. The sandy soil of Zimbabwean could utilize this property of flyash addition in the soil where 70% of the soil are arenosols, inherently least infertile and more prone to leaching, yielding low productivity. The use of sewage sludge/fly - ash combination on agricultural soils is suggested to be a highly promising endeavor from an environmental point of view [44, 49, 55, 56].

4. Conclusion and Recommendations

The global increase in energy demand will lead to more and more flyash in coming years, despite further discarding this byproduct of coal combustion and consuming energy in their disposal process. Strategies should be made to reuse this as a resource in various sectors as much as possible. The utility of flyash is not limited only to the construction sector. Still, many studies have supported its use as a bio - pesticide and increasing the yield of various soil types by its physical and chemical composition. Available studies showed the effect of flyash varies from region to region, influenced by the soil types. Its response is graded on many factors, so it cannot be generalized. Therefore, research on the use of flyash should aim at their characterization by quantifying the plant nutrients available, possible negative effects of flyash on the soil and determining appropriate application quantities in different soil types that enhance crop productivity. In all, much research is needed to recommend flyash as a carrier in bio formulations which could mitigate the environmental crisis of flyash disposal to some extent by increasing its utilization.

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