International Journal of Science and Research Archive

eISSN: 2582-8185

Cross Ref DOI: 10.30574/ijsra

Journal homepage: https://ijsra.net/

(REVIEW ARTICLE)

Check for updates

Comprehensive review on fly ash: Turning waste into a valuable resource for sustainable development

Lal Kumar Chandel [1] and Sheenu Bhadauria [2, *]

[1] *Department of Chemical Sciences, Maharaja Ranjit Singh College of Professional Sciences, Indore, MP, India, 452 001.*
[2] *Department of Chemistry, Kasturbagram Rural Institute, Indore, MP, India, 452 001.*

International Journal of Science and Research Archive, 2024, 12(01), 312–321

Publication history: Received on 22 February 2024; revised on 02 May 2024; accepted on 04 May 2024

Article DOI: https://doi.org/10.30574/ijsra.2024.12.1.0556

Abstract

Fly ash, a byproduct of coal combustion in the power plants has long been viewed as a waste material with potential environmental hazards. However, in recent years, there has been a paradigm shift in the perception of fly ash, as it is increasingly recognized as a valuable resource with numerous applications in field of construction, agriculture, and environmental remediation. This Paper explores the various facets of fly ash and the diverse ways in which it is being harnessed for sustainable development for the society.

Keywords: Fly ash; Soil; Agriculture Soil; Water; Coal; Cement; Concrete; Sustainable development

1. Introduction

The global pursuit of population and economic growth, urbanization and industrialization has inevitably led to an increase in energy demand with coal serving as a primary source of power generation. However, this reliance on coal comes at a cost the production of vast quantities of fly ash, a byproduct laden with environmental challenges. Fly ash, composed of fine particles and potentially harmful elements, poses threats to air quality, water resources, and soil health. Recognizing these challenges, researchers, policymakers, and industries are exploring innovative ways to remediate the pollution caused by fly ash, transforming it into a resource that aligns with principles of sustainability and environmental stewardship.

To comprehend the magnitude of the issue, it is crucial to examine the sheer volume of fly ash generated globally. According to the International Energy Agency, the combustion of coal produced over 850 million tons of fly ash in 2019 alone, contributing to the complex tapestry of environmental pollution. This colossal amount necessitates urgent attention, as the unchecked dispersion of fly ash can lead to severe consequences for ecosystems and human health.

The airborne dispersion of fly ash particles poses a significant threat to air quality. Particulate matter, including respirable particles within the fine fraction of fly ash, can penetrate deep into the respiratory system, causing respiratory and cardiovascular illnesses. The World Health Organization estimates that ambient air pollution, which includes particulate matter from sources like fly ash, contributes to millions of premature deaths annually. Consequently, addressing the airborne pollution caused by fly ash becomes imperative for safeguarding public health and fostering sustainable development.

Fly ash's interaction with water introduces another dimension of environmental risk. Leaching of heavy metals, a common occurrence with fly ash, can contaminate water bodies and groundwater resources. Heavy metals, such as arsenic, lead, and mercury, have detrimental effects on aquatic ecosystems and can potentially find their way into the

*Corresponding author: Sheenu Bhadauria

human food chain. This contamination underscores the urgency of developing remediation strategies that prevent the leaching of harmful substances from fly ash, thereby preserving the integrity of water resources crucial for sustainable development.

As fly ash finds its way into soil through various pathways, the potential consequences for soil health and agricultural productivity cannot be overlooked. The alkaline nature of fly ash can alter soil pH, affecting nutrient availability and disrupting the balance of microbial communities. Additionally, the presence of heavy metals in fly ash can accumulate in soils, posing risks to plant health and human consumption. Sustainable development necessitates a comprehensive understanding of these soil-related challenges and the formulation of remediation approaches that restore soil health and preserve arable land.

Amidst these challenges, a beacon of hope emerges through innovative remediation strategies that aim to convert fly ash from a pollutant into a valuable resource. By adopting sustainable and environmentally friendly practices, fly ash can be harnessed for the betterment of air, water, and soil quality [1-10].

The multifaceted role of fly ash in environmental remediation, from reclaiming degraded lands to encapsulating hazardous waste, underscores its potential as an eco-friendly solution. As research continues to uncover new applications and refine existing techniques, fly ash stands as a testament to the integration of industrial byproducts into sustainable environmental management practices [11].

2. Fly Ash Production

The production of fly ash an integral byproduct of coal combustion plays a significant role in both energy generation and sustainable waste management. Understanding the intricacies of the fly ash production process is essential for harnessing its potential in diverse applications, ranging from construction materials to environmental remediation. As advancements in technology and shifts towards cleaner energy sources continue, the production and utilization of fly ash will likely evolve, contributing to a more sustainable and environmentally conscious future. The production of fly ash involves following steps:

2.1. Coal Combustion

Coal, a fossil fuel, is pulverized into a fine powder to increase its surface area. The powdered coal is then burned in a combustion chamber, typically in a boiler, to produce heat [12].

2.2. Generation of Flue Gases

The combustion process releases hot flue gases that contain a mixture of combustion byproducts, including fly ash. These gases travel through the boiler and other components of the power plants exhaust system, carrying the entrained fly ash particles along with them [13].

2.3. Flue Gas Treatment

Flue gases pass through a series of pollution control devices to reduce emissions of particulate matter, sulfur dioxide (SO_2), nitrogen oxides (NOx), and other pollutants. Electrostatic precipitators or baghouse filters are commonly used to capture fly ash from the flue gases. These devices allow the separation of fine ash particles from the gases [14].

2.4. Fly Ash Collection

The collected fly ash is then transported to storage silos or hoppers for further processing [15].

2.5. Storage and Handling

Fly ash is stored in designated silos or storage areas on-site. It is often transported to other locations for various applications, such as construction or agricultural use.

2.6. Quality Control and Classification

Depending on the specific needs of end-users, fly ash may undergo quality control measures and classification based on its chemical and physical properties. This is particularly important for applications like concrete production.

It's important to note that the composition of fly ash can vary based on the type of coal burned, combustion conditions, and the efficiency of pollution control devices. Generally, it consists of silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), and other trace elements. The specific composition makes fly ash an ideal material for various applications [15- 21]. There are two main types of fly ash

- Class C Fly AshClass C Fly Ash also known as high-calcium fly ash, is produced from burning sub-bituminous or lignite coal. It contains higher levels of calcium and is rich in alumina, silica, and iron oxide and often acts as a self-cementing material. It exhibits pozzolanic and hydraulic properties without the need for additional activators.
- Class F Fly Ash: Generated from burning anthracite and bituminous coals, it is typically low in calcium and possesses both pozzolanic and self-cementing properties.

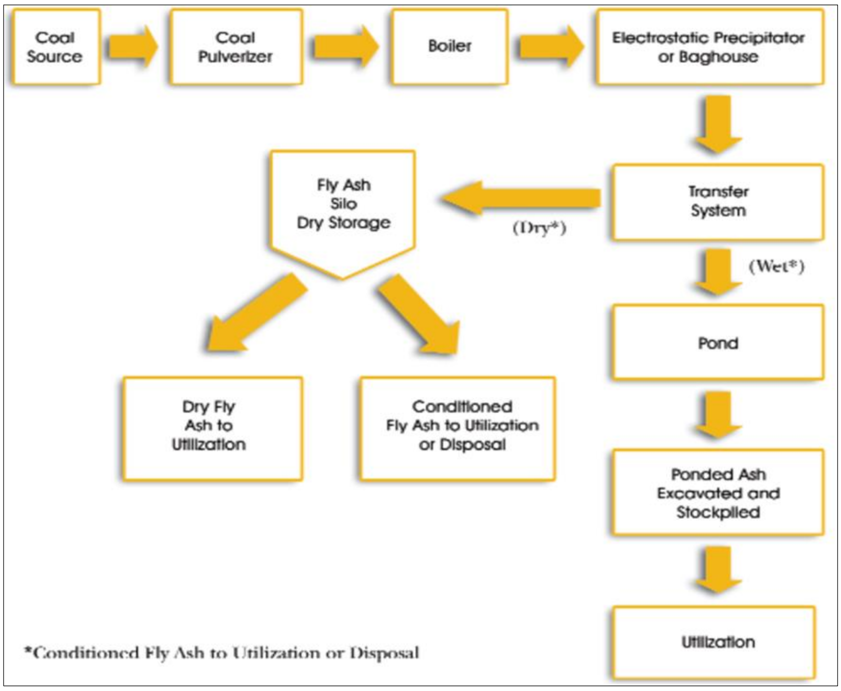

Figure 1 General Fly Ash Production System [22]

3. Application

The utilization of fly ash for environmental remediation and waste management underscores its transformative potential. From stabilizing contaminated soils to encapsulating hazardous waste, soil amendment to improve fertility and structure. In construction industry, where it is employed as a supplementary cementitious material in the production of concrete bricks, blocks, and other building materials. When mixed with Portland cement, fly ash enhances the strength and durability of concrete while reducing the overall carbon footprint. This sustainable alternative to traditional concrete not only makes use of a waste material but also contributes to the conservation of natural resources.

3.1. In Construction

Fly ash's applications in construction, supported by empirical data and research findings, underscore its crucial role in enhancing the sustainability and performance of building materials. As the construction industry continues to prioritize eco-friendly practices, the integration of fly ash is poised to play a central role in shaping a more sustainable and resilient built environment.

3.1.1. Supplementary Cementitious Material (SCM) in Concrete

Fly ash is widely utilized as a supplementary cementitious material (SCM) in the production of concrete. According to a study published in the Journal of Cleaner Production by Geng et al., 2019 [23], incorporating fly ash into concrete mixtures significantly enhances compressive strength and durability. The pozzolanic reactions between fly ash and calcium hydroxide contribute to the formation of additional cementitious compounds, resulting in improved concrete performance.

The use of fly ash in concrete also reduces the environmental footprint associated with cement production. A report by the U.S. Federal Highway Administration (FHWA) states that for every ton of fly ash used in concrete, approximately one ton of carbon dioxide emissions is avoided [24]. This emphasizes the role of fly ash in mitigating the environmental impact of construction activities.

3.1.2. High-Performance Concrete and Reduced Alkali-Silica Reaction (ASR)

Fly ash is instrumental in the development of high-performance concrete (HPC). The American Concrete Institute (ACI) recognizes the benefits of fly ash in HPC, including improved workability, reduced permeability, and increased resistance to chemical attacks [25]. These properties make HPC suitable for challenging construction environments, leading to structures with extended service life and reduced maintenance costs.

Furthermore, fly ash mitigates the risk of alkali-silica reaction (ASR) in concrete. ASR, a chemical reaction that can lead to concrete cracking and degradation, is effectively controlled by the pozzolanic activity of fly ash. Research published in Construction and Building Materials by Montenon et al., 2020 highlights the ability of fly ash to reduce the expansion caused by ASR, thereby enhancing the long-term durability of concrete structures.

3.1.3. Use in Mortars, Grouts, and Stabilization of Soils

In addition to concrete, fly ash is employed in the production of mortars and grouts. Studies have shown that incorporating fly ash in these materials improves workability, reduces water demand, and enhances long-term strength [27]. Fly ash is also utilized for soil stabilization in construction projects. The American Society of Civil Engineers (ASCE) notes that the addition of fly ash to soils enhances their engineering properties, providing increased stability and reducing settling [28]. This application is particularly valuable in infrastructure projects, such as road construction and embankment stabilization.

3.2. In Agriculture

Fly ash, traditionally seen as an industrial byproduct, has found new purpose in agriculture applications, exploring as a valuable resource for enhancing crop productivity through its multifaceted contributions to soil fertility, pH regulation, water retention, and mitigation of heavy metal stress. As agricultural communities seek sustainable alternatives, the incorporation of fly ash into farming practices presents an opportunity to improve yields while addressing environmental concerns associated with industrial byproducts. Continued research and field trials will further elucidate the optimal conditions for the application of fly ash, paving the way for its integration into mainstream sustainable agriculture [29-33].

3.2.1. Soil Amendment for Enhanced Fertility

Fly ash is rich in essential nutrients, making it a valuable soil amendment. Studies have shown that the addition of fly ash to soil improves fertility by providing essential elements for plant growth. According to research published in the Journal of Environmental Management by Singh et al., 2017, fly ash contains significant amounts of potassium, phosphorus, and micronutrients beneficial for plant development [29]. Fly ash emerges as a valuable resource for enhancing crop productivity through its multifaceted contributions to soil fertility, pH regulation, water retention, and mitigation of heavy metal stress. As agricultural communities seek sustainable alternatives, the incorporation of fly ash into farming practices presents an opportunity to improve yields while addressing environmental concerns associated with industrial byproducts. Continued research and field trials will further elucidate the optimal conditions for the application of fly ash, paving the way for its integration into mainstream sustainable agriculture.

Potassium Content

Fly ash often contains potassium, a vital nutrient for plant growth. The incorporation of fly ash into soil contributes to potassium availability, enhancing plant nutrient uptake [34].

Phosphorus Enrichment

The phosphorus content in fly ash makes it an effective source for replenishing soil phosphorus levels. Studies indicate that fly ash-amended soils exhibit improved phosphorus availability, positively influencing crop productivity suggested by Chen et al., 2016 [35].

3.2.2. Neutralization of Acidic Soils

Fly ash's alkaline nature plays a crucial role in neutralizing acidic soils. Acidic soils can hinder plant growth by limiting nutrient availability. The Journal of Environmental Management reports that the application of fly ash in acidic soils helps raise pH levels, creating a more favorable environment for crops [36-37].

3.2.3. Alleviation of Soil Acidity

Many agricultural soils suffer from acidity, which can limit nutrient availability to plants. Fly ash, with its alkaline properties, serves as an effective amendment for neutralizing soil acidity. By raising the pH levels, fly ash creates a more favorable environment for nutrient uptake by plants, thereby promoting improved crop growth and productivity [31].

3.2.4. Enhanced Water Retention

The porous nature of fly ash contributes to improved water retention in the soil. This is particularly beneficial in regions prone to drought or erratic rainfall patterns. The increased water-holding capacity of soils treated with fly ash ensures a more consistent water supply for crops, reducing water stress during critical growth stages and ultimately leading to higher yields [38].

3.2.5. Reduction of Heavy Metal Stress

Fly ash has the ability to immobilize heavy metals in the soil, preventing their uptake by plants. In areas where soil contamination with heavy metals is a concern, the application of fly ash can alleviate stress on crops and contribute to a safer and healthier food supply. This aspect becomes particularly crucial in regions with a history of industrial activities [39].

3.2.6. Sustainable Agricultural Practices

By utilizing fly ash in agriculture, farmers can embrace sustainable practices that not only enhance crop productivity but also contribute to environmental stewardship. The repurposing of fly ash, a byproduct that would otherwise be considered waste, aligns with the principles of circular economy and sustainable resource management in agriculture [29-33].

3.3. Environmental Remediation and Waste Utilization

As global concerns over environmental degradation intensify, the exploration of innovative solutions for ecosystem restoration has become imperative. The various applications of fly ash in ecosystem restoration, highlighting its role in soil rehabilitation, habitat enhancement, and overall environmental revitalization.

3.3.1. Soil Amendment and Erosion Control

Fly ash, known for its fine particle size and nutrient content, proves to be an effective soil amendment. In degraded ecosystems, particularly those affected by mining or construction activities, the application of fly ash helps in stabilizing soil structure, preventing erosion, and promoting vegetation establishment. Its ability to improve soil fertility and structure contributes to the creation of a conducive environment for native plant species to thrive [40].

3.3.2. Habitat Remediation and Biodiversity Enhancement

Ecosystem restoration often involves the rehabilitation of habitats that have been altered or damaged. Fly ash, when strategically applied, can create or enhance habitats for various flora and fauna. Its use in the formation of artificial wetlands or the restoration of degraded landscapes supports biodiversity by providing a substrate for plant growth and attracting a diverse range of species [41].

3.3.3. Phytoremediation Assistance

Contaminated ecosystems, whether affected by industrial pollutants or heavy metals, pose a significant challenge to restoration efforts. Fly ash, with its capacity to immobilize heavy metals in the soil, can assist in phytoremediation initiatives. By reducing the bioavailability of contaminants, fly ash creates a more favorable environment for plants engaged in the remediation of polluted sites [42].

3.3.4. Carbon Sequestration Potential: Fly ash, when used as a soil amendment, can contribute to carbon sequestration. The incorporation of fly ash into degraded soils enhances their organic carbon content, promoting long-term carbon storage. This aspect aligns with global efforts to mitigate climate change by sequestering carbon dioxide from the atmosphere [43].

3.3.4. Creation of Green Infrastructure

Fly ash can play a pivotal role in the development of green infrastructure. Whether used in the construction of artificial islands, green roofs, or urban green spaces, fly ash contributes to the establishment of resilient ecosystems within urban environments. This application enhances overall ecological health and brings nature closer to urban populations.

3.4. Land Reclamation and Stabilization

Fly ash's alkaline nature makes it a valuable agent for land reclamation in degraded and acidic areas. Studies, such as those published in the Journal of Environmental Management by Hettiarachchi et al., 2016, highlight the effectiveness of fly ash in stabilizing soils, preventing erosion, and promoting vegetation growth. The alkalinity of fly ash neutralizes acidic soils, creating a conducive environment for plant establishment [44].

3.4.1. Reclamation of Abandoned Mines

Research indicates that fly ash is effective in reclaiming land degraded by mining activities. The application of fly ash helps stabilize the soil, reducing metal leaching and promoting the establishment of vegetation [45].

3.4.2. Waste Encapsulation and Remediation

Fly ash's pozzolanic properties make it suitable for encapsulating hazardous waste materials. The American Society for Testing and Materials (ASTM) recognizes the potential of fly ash in stabilizing contaminants, reducing their mobility, and preventing leaching into the environment [46].

3.4.3. Heavy Metal Immobilization

Studies, such as those published in the Journal of Hazardous Materials by Li et al., 2016, demonstrate the ability of fly ash to immobilize heavy metals in contaminated soils [47]. Fly ash applications reduce the bioavailability of metals, mitigating the environmental impact of contaminated sites [39].

3.5. Water Quality Improvement

With growing concerns about water quality worldwide, the search for sustainable and effective solutions has become crucial. The various applications of fly ash in addressing water pollution, emphasizing its role in sediment remediation, heavy metal immobilization, and the promotion of sustainable water management practices.

3.5.1. Sediment Remediation in Water Bodies

Fly ash's fine particle size and adsorptive properties make it an effective tool for sediment remediation in water bodies contaminated with pollutants. When applied to sediments, fly ash binds with contaminants, such as heavy metals and organic pollutants, reducing their mobility and preventing their release into the water column. This application contributes to the restoration of aquatic ecosystems and the improvement of overall water quality [48].

3.5.2. Heavy Metal Immobilization

Fly ash has a notable ability to immobilize heavy metals in water, mitigating the adverse effects of metal pollution. Through complexation and precipitation reactions, fly ash reduces the bioavailability of metals, making them less harmful to aquatic organisms. This property is particularly valuable in industrial areas where heavy metal contamination is a significant concern for water quality [49].

3.5.3. Nutrient Filtration and Eutrophication Control

In water bodies affected by nutrient pollution and eutrophication, fly ash can act as a filter to absorb excess nutrients such as phosphorus and nitrogen. By reducing nutrient levels in the water, fly ash helps control algal blooms and improves overall water clarity. This application supports the restoration of aquatic ecosystems and contributes to the prevention of water quality deterioration [50].

3.5.4. pH Stabilization and Acid Mine Drainage Treatment

Fly ash's alkaline properties make it effective in stabilizing the pH of acidic waters, particularly in areas affected by acid mine drainage. The application of fly ash in these environments neutralizes acidity and precipitates metal ions, preventing their leaching into water bodies. This dual action aids in the restoration of water quality in regions impacted by mining activities [51].

3.5.5. Storm water Management and Runoff Control

In urban areas where storm water runoff can carry pollutants into water bodies, fly ash can be utilized in storm water management practices. Its use in permeable pavements and green infrastructure promotes the filtration and absorption of pollutants, preventing their entry into waterways. This application supports sustainable urban water management and protects water quality in increasingly urbanized environments.

3.5.6. Adsorption of Contaminants

Fly ash's porous structure and high surface area enhance its adsorption capacity for various contaminants. It serves as an effective and sustainable material for removing pollutants from water sources [52].

3.6. Challenges and Future Prospects

Annually, Millions of tones fly ash is produced. Which not only require large land area but it is also pollution source of air and water to reduce the problem caused by it. As we know, beneficial uses of fly ash are vast, challenges such as variability in composition, transportation costs, and public perception remain (Fig.2.). Efforts are being made to address these challenges through technological advancements and increased awareness.

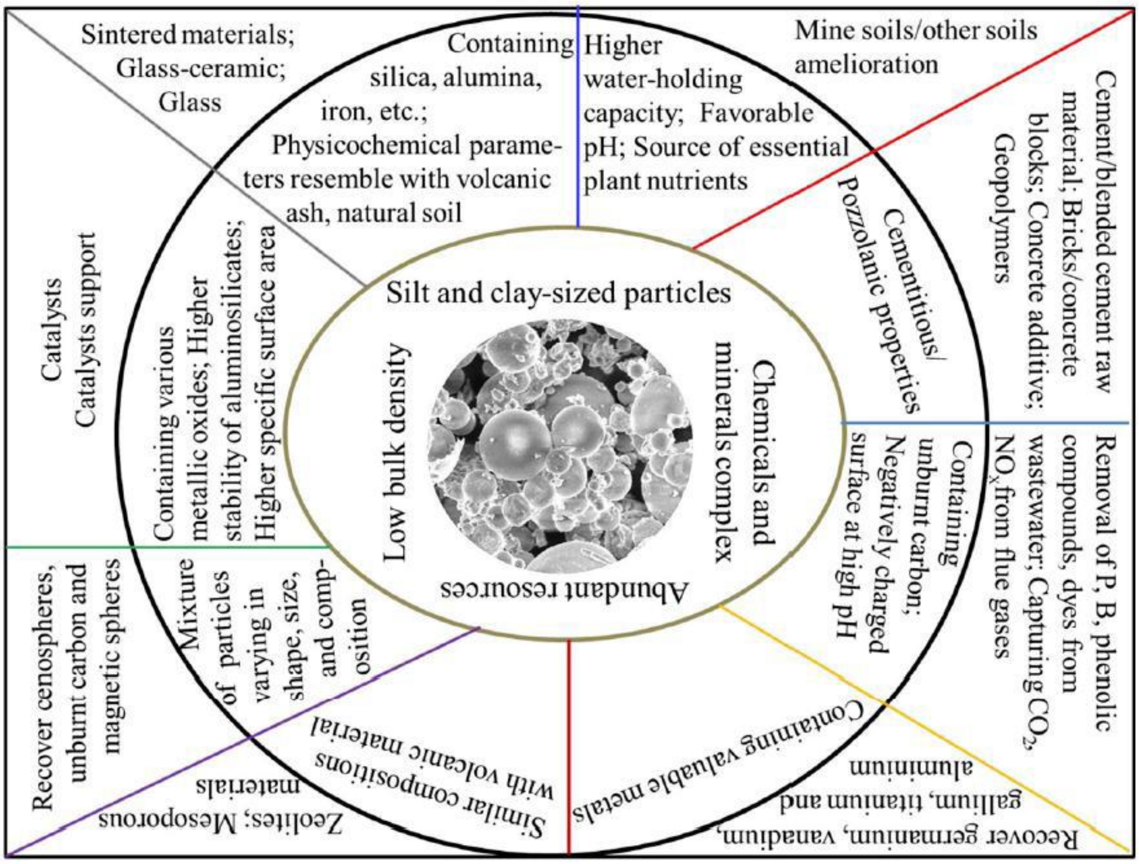

Figure 2 Various Possible ways of fly ash use

4. Conclusion

Fly ash, often viewed as an industrial byproduct, has the potential to be a transformative agent in ecosystem restoration. Its versatile applications in soil amendment, habitat enhancement, phytoremediation support, carbon sequestration, and green infrastructure creation underscore its role as a sustainable tool for environmental revitalization. Continued research and responsible utilization of fly ash in ecosystem restoration projects hold the promise of fostering resilient, biodiversity and ecologically balanced landscapes, contributing to the broader goals of sustainable development and environmental conservation.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Silpa K., Lisa Y., Tata P. B. and Woerden, F. V., (2018) "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050" World Bank Group, Urban Development Series. 1-38p.

[2] Epstein, E., (1997) "The Science of Composting". CRC Press LLC, Florida, 504p.

[3] Scheirs, J. and Kaminsky, W. (2006) "Feedstock Recycling and Pyrolysis of Waste Plastics: Converting Waste Plastics into Diesel and Other Fuels", John Wiley & Sons, 816p.

[4] McDonough, W. and Braungart, M., (2002) "Cradle to Cradle: Remaking the Way We Make Things", North Point Press. New York, 208 p.

[5] Ellen MacArthur, (2012), "Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition", Ellen MacArthur Foundation, 1-112p.

[6] Geyer, R., Jambeck, J. R. and Law, K. L., (2017), "Production, use, and fate of all plastics ever made", Science Advances, 3 (7), e1700782, 5p.

[7] Lundgren, K., (2012), "The Global Impact of E-Waste: Addressing the Challenge", International Labour Organization (ILO) and United Nations University (UNU), Geneva, 1-72p.

[8] Tam, V. W. Y., Tam, C. M. and Le, K. N., (2006), "A review on the viable technology for construction waste recycling", Resources, Conservation and Recycling, 47, (3), 209-221p, Elsevier, Netherlands.

[9] Cherubini, F. and Strømman, A. H., (2011), "Life cycle assessment of bioenergy systems: State of the art and future challenges", Bioresource Technology, 102, (2), 437-451p.

[10] Wilson, D. C., Rodic, L., Cowing, M. J. and Velis, C. A., (2015), "Integrated sustainable waste management in developing countries", Proceedings of the Institution of Civil Engineers - Waste and Resource Management, 168, (1), 26-36p.

[11] Ramezanianpour, A. A., Malhotra, V. M. and Li, V. C., (2014), "Fly Ash-Based Geopolymer: Study of Reaction Products and Reaction Mechanisms", Materials Journal, 111, (5), 499–506p.

[12] i)Steer D. N., (2009), "Geology of Coal Fires: Case Studies from Around the World", Geological Society of America, Environmental and Engineering Geoscience, 15(3), 213-214p. ii) Stracher, G.B., (2004), "Coal fires burning around the world: a global catastrophe", Int. J. Coal Geol. 59, 1–6.

[13] Mastellone, M. L. (2002), "Combustion and Co-combustion of Biomass: Fundamentals, Technologies, and Primary Measures for Emission Reduction", Energy and Fuels, 16(1), 6–16p.

[14] i) ASTM C 618, Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete, ASTM International, West Conshohocken, PA, USA (2012), ii) T. L. Robl, J. G. Groppo, Method for hydraulically separating carbon and classifying coal combustion ash, United States Patent (Patent No: US 7,963,398 B2) (2011).

[15] Saidur, R., Abdelaziz, E. A., Demirbas, A., Hossain, M. S. and Mekhilef, S., (2011), "A review on biomass as a fuel for boilers", Renewable and Sustainable Energy Reviews, 15(5), 2262–2289p.

[16] Ramezanianpour, A. A., Malhotra, V. M. and Li, V. C., (2014), "Fly Ash-Based Geopolymer: Study of Reaction Products and Reaction Mechanisms", Materials Journal, 111(5), 499–506p.

[17] Thomas, M. D. A., Gupta, R. C. and Muan, A. (2013), "Pozzolanic and cementitious reactions of fly ash in blended cement pastes" Cement and Concrete Composites, 37, 60–70p.

[18] Mehta, P. K., and Monteiro, P. J., (2014), "Concrete: Microstructure, Properties, and Materials", 4th Edition, McGraw-Hill Education, 1-684p.

[19] American Concrete Institute (ACI), (2017), "Report on the Use of Raw or Processed Natural Pozzolans in Concrete", ACI 232.2R-17.

[20] Geng, G., Zhang, W. and Hwang, K., (2019), "Effects of fly ash and slag on the properties of self-compacting concrete", Journal of Cleaner Production, 238, 117893.

[21] Kumar, S., Samadder, S. R. and Khan, D., (2017), "Fly ash characterization, utilization and government initiatives in India: A review" Journal of Environmental Management, 186, 376–386p.

[22] ASTM International. (2019). ASTM C618-19 Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.

[23] Geng, G., Zhang, W. and Hwang, K. (2019), "Effects of fly ash and slag on the properties of self-compacting concrete", Journal of Cleaner Production, 238, 117893.

[24] Federal Highway Administration (FHWA)., (2015). Sustainable Pavements: A Guide to Developing Environmentally Friendly Pavements.

[25] American Concrete Institute (ACI)., (2006). Guide for the Use of High-Performance Concrete.

[26] Montenon, B., Kim, Y. M. and Rios, S., (2020), "Control of alkali–silica reactivity in mortars using fly ash as partial cement replacement", Construction and Building Materials, 234, 117388.

[27] Mehta, P. K. and Monteiro, P. J., (2014). Concrete: Microstructure, Properties, and Materials. McGraw-Hill Education, 1-675p.

[28] American Society of Civil Engineers (ASCE). (2018). "Standard Practice for the Use of Fly Ash in Soil Stabilization", American Society of Civil Engineers, 1-81p.

[29] Singh, A. K., Rai, U. N., Singh, N. K. and Upadhyay, A. K., (2017) "Assessment of nutrient and heavy metal content in fly ash and its suitability for agronomic land use", Journal of Environmental Management, 186, 1–8p.

[30] Pathak, H., Rao, D. L. N. and Pal, D. K. (2007), "Effect of fly ash incorporation on soil physical properties and productivity of soybean and wheat crops in vertisols", Bioresource Technology, 98(3), 592-599p.

[31] Samal, A., Maiti, S. K. and Patnaik, U. S. (2011), "Effect of fly ash on soil properties and crop productivity in a vertisol" International Journal of Environmental Science and Technology, 8(4), 831-840p.

[32] Pathak, H., Rao, D. L. N. and Pal, D. K., (2007). Effect of fly ash incorporation on soil physical properties and productivity of soybean and wheat crops in vertisols. Bioresource Technology, 98(3), 592-599p.

[33] Malhotra, V. M. and Mehta, P. K., (2002), "Use of fly ash in agriculture: An overview", Resource Conservation and Recycling, 36(3), 197-205p.

[34] Tiwari, A., Adhikari, M., Parihar, P. S. and Singh, N. (2018), "Evaluation of fly ash for improving physicochemical and microbial properties of a sodic soil", Environmental Science and Pollution Research, 25(35), 35464–35472p.

[35] Ram, L.C. and Masto R.E., (2014), "Fly ash for soil amelioration: A review on the influence of ash blending with inorganic and organic amendments", Earth-Science Reviews, 128, 52-74p.

[36] Kumar, A., Dhanwal, N., Meena, V. S. and Dubey, R. C., (2016), "Characterization and utilization of fly ash of NTPC Dadri, Uttar Pradesh in agriculture", International Journal of Recycling of Organic Waste in Agriculture, 5, (3), 197–208p.

[37] Rashid, M. I., Mujawar, L. H., Shahzad, T., Almeelbi, T., Ismail, I. M. I. and Oves, M., (2016), "Bacteria and fungi can contribute to nutrients bioavailability and aggregate formation in degraded soils", Microbiological Research, 183, 26-41p.

[38] Golla, R. S. and Raju, G. V. R., (2019), "Influence of fly ash application on water retention characteristics of soil", Materials Today: Proceedings, 18, 3145-3150p.

[39] Ghosh, M. and Singh, S. P., (2005), "A review on phytoremediation of heavy metals and utilization of its byproducts", Applied Ecology and Environmental Research, 3, (1), 1-18p.

[40] Malhotra, V. M. and Mehta, P. K., (2002), "Use of fly ash in agriculture: An overview" Resource Conservation and Recycling, 36, (3), 197-205p.

[41] Zand, A. D., Bazrafshan, E. and Entezari, M. H., (2018), "Utilization of fly ash in environmental applications: A review" Journal of Environmental Management, 213, 351-361p.

[42] Li, Y., Zhang, W., Zhang, C. and Wang, L. (2016), "Immobilization of heavy metals in sewage sludge during the pyrolysis and hydrothermal carbonization process", Bioresource Technology, 218, 420-427p.

[43] Ukwattage, N. L., Ranjith, P. G., Bouazza, M. and Law, M. C., (2015), "Sequestration of carbon dioxide (CO2) utilizing mineral carbonation technology applied to concrete waste: A sustainable solution for reducing the carbon footprint of the construction industry", Journal of Cleaner Production, 103, 349-359p.

[44] Hettiarachchi, G. M., Pierzynski, G. M. and Kwon, T., (2016), "Sustainable land application of coal combustion residual (CCR) materials: Mechanisms controlling trace element release and metalloid attenuation", Journal of Environmental Quality, 45, (1), 228–237p.

[45] Ettler, V., Mihaljevič, M., Šebek, O. and Mapani, B., (2016), "Coal fly ash as a resource for rare earth elements", Environmental Science and Technology, 50, (5), 2685–2693p.

[46] ASTM International. (2019). ASTM C618-19: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.

[47] Li, H., Dong, X., da Silva, E. B., de Oliveira, L. M. and Chen, Y., (2016), "Use of fly ash and other waste materials in heavy metal stabilization in simulated MSW landfills", Journal of Hazardous Materials, 301, 202–211p.

[48] Ramakrishnaiah, C. R. and Govil, P. K., (2002), "Evaluation of water quality index for drinking water", Journal of Environmental Science & Engineering, 44, (3), 195-207p.

[49] Yuan, Y., He, H., and Yang, S. S., (2012), Stabilization of heavy metals in water hyacinth compost and their availability in an acid environment. Journal of Hazardous Materials, 217-218, 272-279p.

[50] Khan, M. A., Ghosh, S., and Strezov, V., (2016), "Thermal behavior of biomass and biomass components during Pyrolysis", Energy Conversion and Management, 115, 207-219.

[51] Panda, G. K., and Nayak, P. (2016), "Reclamation of degraded water by alkaline-stabilized fly ash", Journal of Water Reuse and Desalination, 6,(4), 537-544.

[52] Christy, C. F. and Tensing D., (2011), "Greener Building material with fly ash", Asian journal of civil engineering (Building and Housing), 12, 87-105p.