JPPIPA 9(9) (2023)

Jurnal Penelitian Pendidikan IPA

Journal of Research in Science Education

http://jppipa.unram.ac.id/index.php/jppipa/index

Utilization of Fly Ash Waste in the Cement Industry and its Environmental Impact: A Review

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Received: July 1, 2023
Revised: September 9, 2023
Accepted: September 25, 2023
Published: September 30, 2023

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DOI: 10.29303/jppipa.v9i9.4504

Abstract: The cement industry is one of the most important industries in the development of a country. However, the production activities of the cement industry also cause significant environmental impacts, one of which is air pollution. One of the by-products of fuel combustion in the cement industry is fly ash, which if not managed properly can pollute the air and the surrounding environment. This research aims to provide an overview of the environmental impacts of using fly ash in the cement industry, especially in relation to air pollution. This research uses the literature review method, which is by collecting and reviewing literature or documents related to the research topic. The data sources used in this research are scientific journals, books, and other related documents. Data analysis in this study was carried out by reviewing and examining literature or documents related to the research topic, then summarizing and compiling the results of the analysis into an overview. Based on the results of this study, it can be concluded that the use of fly ash in the cement industry has significant environmental impacts, especially related to air pollution. However, there are several technologies and fly ash processing methods that can reduce the environmental impact of cement industry production activities, such as the use of fly ash as raw material for making lightweight concrete or as raw material for the production of other building materials.

Keywords: Cement industry; Environment; Fly ash; Impact

Introduction

Fly ash is generally generated from the electricity production process. Coal fly ash, or commonly referred to as coal fly ash (CFA), is a by-product of burning pulverized coal in thermal power plants. Depending on the type and quality, FA consists of different proportions of oxides-mostly silica, alumina, and calcium-and can exhibit pozzolanic activity. Fly ash with pozzolanic properties makes it possible to substitute cement and fine aggregate in concrete (Marinković & Dragaš, 2018). Coal fly ash is generated in coal-fired power plants and steam power plants when coal is crushed and blown with air into the combustion chamber of a boiler, which quickly ignites, generates heat and produces a liquid mineral residue (see Figure 1). The heat is removed from the radiators through the boiler tubes to cool the gas lines and solidify the developed liquid minerals and then discharged as ash. State the objectives of the work and provide an adequate background, avoiding a detailed literature survey or a summary of the results.

Some elements are commonly found in coal: B, Br, Cd, C1, Hg, I, Pb, Sb, and Se (Meij, 1994). The waste of fly ash produced from the combustion of coal consists of components SiO_2, Al_2O_3, CaO, Na_2O, Fe_2O_3, MgO, K_2O, and other metal oxides (Lu et al., 2023). Other minor components found in fly ash are Cr, Cd, Pb, and Hg (Yu et al., 2022). Fly ash is an industrial by-product known as environmental pollutants (Adriano et al., 1980).

Fly ash in some countries is categorized as waste. Fly ash is still a problem in many countries due to the dependence on coal energy. Based on statistical data, the total production of fly ash globally is 1,200 MT (Yang et al., 2021). In Indonesia, according to the 2020 energy mix, coal fuel consumption dominates at 38%. According to data from the ESDM Ministry, coal remains the main source of energy, especially for power plants, which increased from 2009 to 2019. Domestic coal consumers for power generation in 2019 were recorded at 98.5

How to Cite:
Permatasari, R., Sodri, A., & gustina, H.A. (2023). Utilization of Fly Ash Waste in the Cement Industry and its Environmental Impact: A Review. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 569–579. https://doi.org/10.29303/jppipa.v9i9.4504

million tons of coal (71%) and the rest for the industrial sector. The largest coal consumer today is the power generation sector, where the majority of coal-fueled PLTUs are used in almost the entire territory of Indonesia. This shows that the largest bulk of fly ash and bottom ash waste comes from the power generation sector. The estimated waste of fly ash and bottom ash (FABA) produced from the total of each coal combustion reached 5% (Anggara et al., 2021). Coal combustion results in the redistribution of elements to about 25% bottom ash and 75% fly ash (Kitto & Stultz, 2005). Monthly data on fly ash and bottom ash waste in PLTU based on PT PLN data for 2020 is shown in Figure 2.

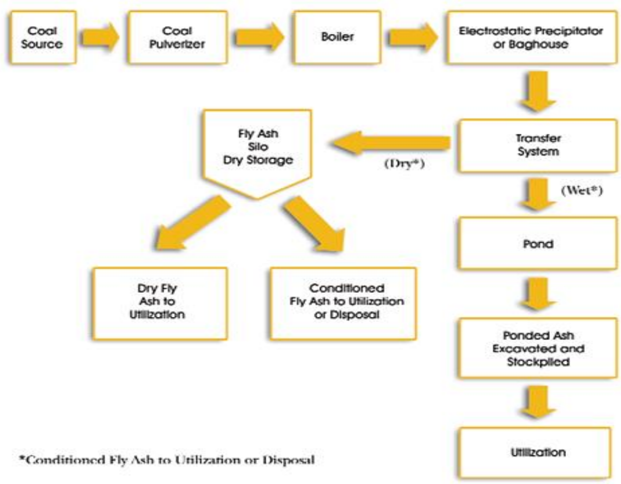
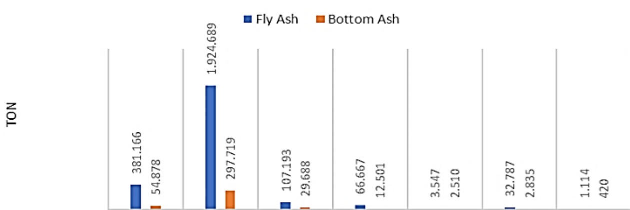


Figure 1. Process flow of fly ash production and utilization (American Coal Ash Association, 2003)



	Sumatera	Jawa	Kalimantan	Sulawesi	Maluku	Nusa Tenggara	Papua
Fly Ash	381.166	1.924.689	107.193	66.667	3.547	32.787	1.114
Bottom Ash	54.878	297.719	29.688	12.501	2.510	2.835	420

Figure 2. Fly ash and bottom ash waste generation at power plant

The increasing production of fly ash utilization rate is only about 60% (Yang et al., 2021). To reduce the amount of fly ash generation, one alternative utilization with a large absorption is in the cement industry for raw materials for making cement. The utilization of fly ash in countries such as China, India, the United States, and the European Union is still in the early stages of commercialization and further research is needed to optimize fly ash processing and explore underutilized applications (Yao et al., 2015).

Sommerville et al. (2013) stated that the utilization of fly ash and bottom ash waste in the world is generally low, reaching only 25% of the total amount of coal ash produced, while the remaining 75% is wasted as waste and causes pollution. Meanwhile, in Indonesia the utilization rate of fly ash is only 10-12%, of this percentage 73% is processed on the island of Java, on other islands the fly ash utilization rate is below 30% (Ekaputri et al., 2020). The comparison of fly ash utilization in the world and in Indonesia is shown in Figure 3 and 4.

With the increasing production of fly ash and the low utilization rate of fly ash, therefore, the purpose of this paper is to analyze the utilization of fly ash in the cement industry where the waste absorption is the highest. In addition, we also analyze the environmental impact caused by the use of fly ash waste in the cement industry.

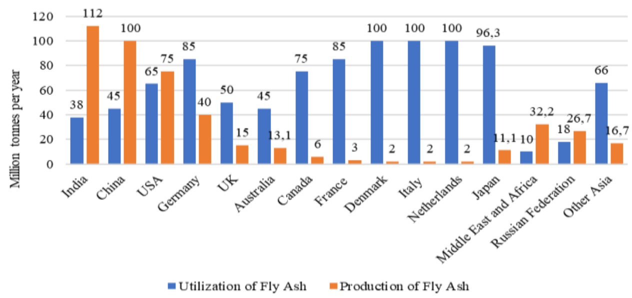


Figure 3. Trend of fly ash utilization across the globe (Gollakota et al., 2019)

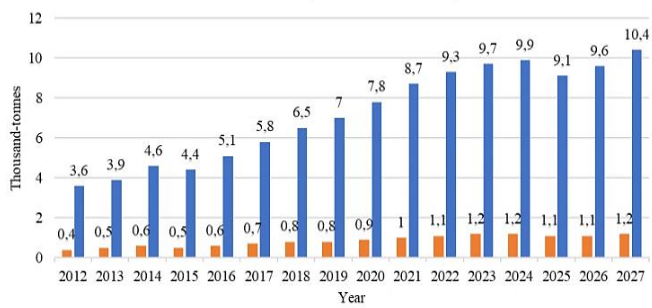


Figure 4. Trend of fly ash utilization in Indonesia

Method

This research uses the literature study method, which is a method of collecting data and reviewing literature or documents related to the research topic. Document study is a data collection technique through the use of references from books to obtain opinions, theories, and research results related to research problems. The data sources used in this research are scientific journals, books, and other related documents. Data analysis in this research is carried out by reviewing and examining literature or documents related to the research topic, then summarizing and compiling the results of the review into an overview.

Properties and Classification of Coal Fly Ash

Properties of Coal Fly Ash

Understanding the physical, chemical, and mineralogical properties of coal fly ash is important, as these properties affect its subsequent use and disposal. The specific properties depend on the type of coal used, combustion conditions, and collector arrangement, among other factors (Yao et al., 2015). Fly ash physically consists of small particles that fly away with the combustion gases (Marinković & Dragaš, 2018). Fly ash has pozzolanic properties, which is a material that contains silica or silica and alumina and can react chemically with calcium hydroxide at ordinary temperatures to form cementitious compounds (Marthinus et al., 2015).

Coal fly ash is one of the most complex materials. The particle size of fly ash can vary depending on the type of coal used and the combustion process performed. Physically, fly ash is fine particles with an average size of b20 μm and has a low to medium bulk density (0.54-0.86 g/cm^3), high surface area (300-500 m^2/kg) and light texture. The main components of fly ash are metal oxides with varying unburned carbon content measured by loss on ignition (LOI) tests. The major oxide contents are usually in descending order: $SiO_2 > Al_2O_3 > Fe_2O_3 > CaO > MgO > K_2O$. Fly ash also contains many elements, some of which are environmental concerns. Based on the Ca/S ratio and pH value, fly ash can be classified into three main groups: highly alkaline ash (pH 11-13) mildly alkaline ash (pH 8-9) and acidic ash (Yao et al., 2015). The chemical composition of fly ash can also vary depending on the type of coal used and the combustion process performed. The heavy metal content in fly ash can vary depending on the type of coal used and the combustion process carried out. The chemical composition of fly ash according to several studies can be seen in Table 1.

Classes of Fly Ash

The classification standards for flying ashes are different in each country. Flying coal is composed of class F, class C, and class N as defined by ASTM C618 (ASTM C618-03, 2003). The classification standard based on ASTM C618-19 refers to the content of several chemical components that can be seen in Table 1.

Class F Fly Ash

Class F fly ash is usually produced from burning anthracite or bituminous coal, but can also be produced from subbituminous coal and from lignite (ASTM C618-12A, 2014). Class F fly ash contains high levels of silica, alumina and iron. It is usually produced from burning bituminous and sub-bituminous coal. This type of fly ash has strong pozolanic properties and is commonly used in the manufacture of cementless concrete (geopolymer) or as an additive in concrete mixes to improve strength and durability (Kaya et al., 2020).

Class C Fly Ash

Class C fly ash is usually produced from burning lignite or subbituminous coal, and can also be produced from anthracite or bituminous coal. Class C fly ash typically has a total calcium content, expressed as calcium oxide (CaO), that is higher than Class F fly ash (ASTM C618-12A, 2014). Some Class C fly ashes may contain lime contents higher than 10% (ASTM C618-03, 2003). Class C fly ash has higher calcium oxide (CaO) content than Class F fly ash. It is usually produced from burning sub-bituminous and lignite coal. This type of fly ash has weaker pozolanic properties and can be used in concrete mixes as a partial replacement for cement to improve concrete performance (Kaya et al., 2020).

Table 1. Chemical Composition of Fly Ash According to Some Research

Component	(Kong et al., 2007)	(Temuujin & Riessen, 2009)	(Thokchom et al., 2009)	(Mustafa Al Bakria et al., 2011)	(Al Bakri Abdullah et al., 2013)	(Hardjito et al., 2016)
SiO_2	48.8%	-	56.01%	52.11%	26.4%	47.8%
Al_2O_3	27%	23.63%	29.8%	23.59%	9.25%	24.4%
Fe_2O_3	10.2%	15.3%	3.58%	7.39%	30.13%	17.4%
TiO_2	1.3%	1.32%	1.75%	0.88%	3.07%	1.328%
CaO	6.2%	1.74%	2.36%	2.61%	21.6%	2.42%
MgO	1.4%	1.2%	0.3%	0.78%	-	1.19%
Na_2O	0.37%	0.38%	0.61%	0.42%	-	0.31%
BaO	0.19%	-	-	-	-	-
SrO	0.16%	-	-	-	-	-
K_2O	0.85%	0.84%	0.73%	0.8%	2.58%	0.55%
P_2O_5	1.2%	1.31%	0.44%	1.31%	0.67%	2%
SO_3	0.22%	0.28%	Nil	0.49%	1.3%	0.29%
MnO	0.15%	0.13%	-	0.03%	-	0.12%
ZrO_2	-	-	-	-	-	-
LOI	1.7%	1.78%	0.4%	-	4.34%	1.1%

Class N Fly Ash

Class N fly ash in concrete mixtures entails raw or calcined natural pozzolan such as some diatomaceous earths; opaline chert and shale; volcanic or pumice tuff and ash, calcined or uncalcined; and various materials that require calcination to induce satisfactory properties, such as some clays and shales (ASTM C618-12A, 2014).

Table 2. Chemical Composition of Fly Ash in America and China

Chemical Composition (%)	Class of Fly Ash in Amerika (ASTM C618-03, 2003)			Class of Fly Ash in China (Lu et al., 2023)	
	F	C	N	F	C
SiO2 + Al2O3 + Fe2O3 (min)	70	50	50	-	-
CaO	Negligible (report only)	18 (max)	>18	<10	≥10
SO3 (max)	4	5	5	-	-
Moisture (max)	3	3	3	-	-
LOI (max)	10	6	6	-	-

Classification of fly ash waste is important to understand its characteristics and potential utilization. In addition, the management of fly ash waste must also pay attention to applicable regulations and standards, especially regarding the management and disposal of waste that can affect the environment and human health. The use of fly ash as a raw material in cement production has several advantages. One of the advantages is that the use of fly ash can reduce dependence on the main raw materials, such as limestone and clay, which are increasingly difficult to obtain and expensive (Saputra, 2019). In addition, the use of fly ash can increase concrete strength, reduce permeability and water permeability, and improve corrosion resistance (Olii et al., 2023).

Application of Fly Ash Waste Utilization in Cement Industry

In the context of waste utilization, the use of fly ash as an alternative raw material in the cement industry is at the co-processing stage. The use of waste as an alternative raw material and thermal process fuel is known as co-processing. Co-processing is the process of treating industrial waste by using the waste as fuel and raw material in cement production. In co-processing, industrial waste is mixed with conventional fuels such as coal and used as fuel in cement kilns. Industrial waste can also be used as a raw material in cement production, replacing conventional raw materials such as limestone and clay (Baidya et al., 2016). Waste co-processing can also be used as a substitute for fossil fuels and plays an important role because with rapid population growth and economic development, waste production has increased rapidly especially in rapidly developing countries. The cement industry can utilize waste as an alternative fuel and raw material, thereby reducing the use of fossil fuels while benefiting society by reducing the need for waste incineration or landfilling (WBCSD, 2015). Therefore, it can be said that co-processing provides dual benefits by providing waste handling solutions and energy efficiency.

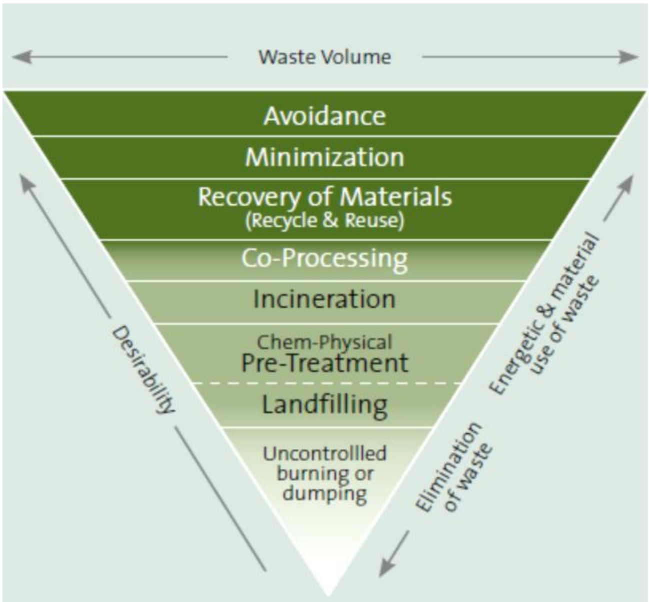


Figure 5. Waste management hierarchy (Hasanbeigi et al., 2012)

Co-processing has several advantages. First, it can reduce waste going to landfills and reduce greenhouse gas emissions resulting from burning conventional fuels. Second, it can save conventional fuels and reduce production costs. Third, it can improve production efficiency and the quality of cement products (Tiwary et al., 2014). Co-processing is an effective solution for waste management and energy recovery with great economic benefits. Co-processing can also help industries meet carbon emission reduction targets, as the use of alternative fuels can reduce greenhouse gas emissions. In addition, co-processing can also reduce the use of new raw materials and conventional fuels, thereby reducing the carbon footprint of the cement plant and the waste-generating industries served by the plant (Baidya et al., 2017). There are supply chain implementation barriers to co-processing, including waste availability, waste transportation and storage, technology installation requirements, waste composition, clinker quality, emission factors, and government support. Baidya et al.

(2016) in their research then mentioned that if these problems can be overcome, then the co-processing process can be a solution to the management of clinker. Co-processing can be an effective and sustainable waste management solution for densely populated countries like India.

Utilization of B3 Waste according to Environmental and Forestry Government Regulations Number 6 of 2021 is an activity of reuse, recycling, and/or recovery that aims to convert hazardous waste into products that can be used as substitutes for raw materials, auxiliary materials, and/or fuel that are safe for human health and the environment (KLHK, 2021a). Utilization of non-hazardous waste is the activity of reuse, recycling, and/or recovery that aims to convert non-hazardous waste into products that can be reused in a way that is safe for human health and the environment (KLHK, 2021b). Replacing cement with fly ash can significantly reduce social, environmental and economic impacts. If all fly ash produced in China could be used effectively, it could save as much as 150 billion CHY, and reduce 560 million tons of CO_2 (Wang et al., 2017).

Research on the utilization of fly ash waste as raw material for product mixtures has been widely carried out, including its role as an absorbent in removing organic pollutants from wastewater (Ahmaruzzaman, 2009), aggregate substitutes in paving block production (Winarno et al., 2019), concrete (Umboh et al., 2014; Sapulete et al., 2018; Kusdiyono et al., 2017), paving and brick (Ekaputri et al., 2019), absorbent to neutralize acid mine drainage (Gobel et al., 2018). Fly ash and bottom ash waste can also be utilized as a base layer for road pavement (Indriyati et al., 2019), reinforced concrete bricks (Sulistyowati, 2013), ceramic mixture (Luo et al., 2017) and ceramic products derived from fly ash waste and clay (Namkane et al., 2016). The utilization of fly ash from coal-fired power plants in various sectors is essential to reduce the environmental burden caused by fly ash storage and disposal. Fly ash has physicochemical properties that can be utilized in the construction, composite, and geopolymer material production sectors. The addition of fly ash to metal-matrix composites has shown improved wear resistance and better corrosion behavior.

Fly ash has also been used in thermal spray coating techniques to improve the surface properties of metal substrates, such as wear resistance and corrosion resistance (Mathapati et al., 2021). Fly ash can be used in land reclamation of former coal mines. By combining fly ash with soil, it can help improve soil structure and increase the ability of land to support plant growth (Ferdian et al., 2023). Fly ash can be used as a mixed material in the manufacture of lightweight concrete bricks. These bricks have good strength, high thermal insulation, and contribute to energy savings (Haryanti, 2017). Fly ash can be used as a material to form a strong and stable landfill foundation (Aditya, 2019). Besides, fly ash can be used as a mixed material in the production of wall panels that have good acoustic and thermal insulation (Hadipramana & Syahputra, 2019).

Fly Ash as Cement

The cement industry does have a very important role in infrastructure development, especially in the construction of buildings, roads, bridges, and so on. Cement is used as the basic material for making concrete and mortar, which are the main building materials (Pandeleke, 2014). Therefore, the existence of the cement industry is very important in meeting the increasing infrastructure needs along with population growth and urbanization. Fly ash utilization is important because the problem of fly ash waste generation becomes more serious when considering the amount of unused fly ash stored in ash ponds near thermal power plants (Rastogi & Paul, 2020). Fly ash can be used as an admixture in the manufacture of concrete. The use of fly ash in concrete can increase the strength, resistance to chemical attack, and long-term performance of concrete (Nugroho, 2010). Besides, fly ash can be used as an admixture in asphalt production. It can improve stability, resistance to deformation, and road service life (Kartikasari & Hartantyo, 2017).

One alternative utilization of fly ash waste is in the cement industry. The utilization of fly ash waste as an alternative raw material in the cement industry must meet the criteria for the specified component compounds. There are several types of fly ash utilization products into cement including portland cement (Nurwaskito et al., 2015), composite portland cement (Al Bakri et al., 2012; Purnawan & Prabowo, 2017; Putra et al., 2020), pozzolanic portland cement (Romli, 2020; Waani & Elisabeth, 2017), hydraulic cement, and so on. The PUPR ministry issued an approval for the use of fly ash and bottom ash waste as preferred backfill and foundation layers (PUPR, 2022), while BSN published in SNI 9092: 2022 (Badan Standarisasi Nasional, 2022). Research by Pratiwi et al. (2020) where the resulting product in the form of High Volume Fly ash (HVFA) concrete can replace cement composition up to 80%. The utilization of fly ash waste in the cement industry is at the co-processing stage which is used as an alternative raw material that provides economic benefits to the cement industry. The utilization of fly ash waste is economically beneficial in the manufacturing process but has an impact on the environment.

Environmental Impact Evaluation in Cement Industry

Coal contains a large amount of metals, and after combustion, the concentration of metals in fly ash is sometimes 4-10 times higher than the concentration of metals in the parent coal. Coal fly ash has been viewed as a major potential source for releasing many environmentally sensitive elements into the environment, many factors, such as particle size, initial concentration of elements, pH of extraction solution, leaching time, and solid/liquid ratio affect the mobility of elements in aqueous environments (Saikia et al., 2006). The environmental impact of coal fly ash has been fully recognized. Research by Sulasmi et al. (2022) found that cement industry activities have a significant negative impact on the environment and surrounding communities, such as noise, dust, health problems, house damage, drought, and loss of water sources. Most ash disposal methods eventually lead to the dumping of fly ash on open land. Irregular piling and improper disposal of fly ash will lead to its disposal on large areas of land, resulting in soil degradation and hazards to human health and the environment. Fly ash particles, which are small enough to escape emission control devices, are easily suspended in the air and are a major source of gas pollution. Repeated exposure to fly ash can cause irritation to the eyes, skin, nose, throat and respiratory tract, and can even result in arsenic poisoning. Fly ash can even reach underground and eventually cause siltation, clogging natural drainage systems and contaminating groundwater with heavy metals (Yao et al., 2015).

The process of burning coal to produce fly ash can cause the release of greenhouse gases into the atmosphere. Greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrogen dioxide (NO_2) can contribute to global climate change. The accumulation of these gases in the atmosphere can lead to global warming, temperature changes, and undesirable changes in weather patterns (Fansuri, 2019). However, the negative environmental impact of fly ash in the cement industry can be overcome by proper treatment (Bajpai et al., 2020). Fly ash treatment technologies and methods that have been developed can reduce the content of fine particles and utilize fly ash as a raw material for the manufacture of lightweight concrete or as a raw material for the production of other building materials. In this way, fly ash can be optimally utilized and the environment can be protected from air pollution (Gamage et al., 2011). Fly ash treatment is one of the solutions to reduce the environmental impact of using fly ash in the cement industry. There are several processing technologies and methods that can be used, such as thermal processing, acid dissolution, and the manufacture of alternative building materials. Thermal treatment is one of the fly ash treatment methods that can change the physical and chemical properties of fly ash. This method can produce fly ash that is more stable and can be used as raw material for making lightweight concrete (Wons et al., 2018). Acid dissolution is a fly ash processing method that can remove heavy metals from fly ash, so that it can be used as raw material for making alternative cement (Dontriros et al., 2020). In addition, making alternative building materials is also one of the options for processing fly ash to reduce air pollution. The ash can be used as raw material for the production of bricks, paving blocks, and other building materials. This can reduce the use of natural raw materials such as bricks and concrete, and reduce the environmental impact of the cement industry (Sandanayake et al., 2020).

Fly ash waste that pollutes the environment can disrupt biodiversity. Living organisms such as animals, birds, and insects can be exposed to the chemical compounds contained in fly ash waste, either through food, water, or direct contact. This can lead to population decline, behavioral changes, or even death in some species (Wahyudi, 2022). If fly ash waste is not managed properly, soil pollution can occur around the disposal area. The harmful chemical compounds in fly ash can pollute the soil, disrupt soil fertility, and affect plant growth (Saidy & SP, 2021). If the soil is contaminated by fly ash waste, plants growing in the area may absorb harmful compounds through their roots and acquire contents that are potentially harmful to the health of humans and animals that consume them (Darmayani et al., 2023).

Fly ash also contains harmful chemical compounds such as heavy metals (e.g., lead, mercury, cadmium) and organic compounds that can affect human health and ecosystems. Long-term exposure to these compounds can cause poisoning and serious health problems (Xue & Liu, 2021). Fly ash contains very small particles and can be dispersed in the air easily. These particles can be inhaled by humans and animals, and can affect their respiratory systems. If inhaled in large enough quantities, the particles can cause irritation to the respiratory tract, impair lung function, and can even cause more serious health problems. In addition, fly ash can also affect the air quality around the cement industry. If fly ash is disposed of improperly, the particles can be carried by the wind and dispersed into the surrounding environment. This can lead to a decrease in air quality around the cement industry, which can affect the health and comfort of the surrounding community (Lahiri, 2022). Study by Afifah (2014) concluded that the PT Semen Indonesia factory in Temandang Village had a holistic negative impact on the community, including natural resource scarcity, social and cultural changes, environmental damage, employment marginalization, and compensation issues.

Fly ash contains fine particles such as PM2.5 (particles less than 2.5 micrometers in diameter) and PM10 (particles less than 10 micrometers in diameter). These particles can be inhaled by humans and animals, enter the respiratory tract, and cause health problems such as lung irritation, respiratory disorders, and heart disease (Muji & Wahyudi, 2018). If fly ash waste is not managed properly, there can be water pollution around the disposal site or the waste dissolved in water. Chemical compounds from fly ash such as heavy metals can contaminate water sources, threaten the sustainability of aquatic ecosystems, and disrupt aquatic life (Febriyani, 2022). Uncontrolled disposal of fly ash waste can affect surface and groundwater quality. Changes in pH, increased heavy metal content, and other chemicals can damage aquatic ecosystems and disrupt the lives of aquatic organisms (Mufrodi et al., 2008).

Result and Discussion

The cement industry is one of the industries that has an important role in infrastructure development. So the cement industry has a key role in the availability and manufacture of cement, concrete, which is an important material in the construction of buildings, roads, bridges, and other infrastructure. The increasing need for coal fuel in line with the increase in fly ash waste, cement industry companies need to improve programs and implementation to reduce negative impacts on the environment and society, and increase awareness of the impact of their industrial activities on the environment. The government also needs to monitor the condition of communities around industrial areas and enforce stricter regulations to reduce the negative impacts of the cement industry on the environment and communities.

The utilization of fly ash also brings ecological and economic benefits because it can reduce waste materials and save energy. However, if fly ash is not managed properly, it can have a negative impact on the surrounding environment (Munir, 2008). Fly ash can pollute the air and soil, and interfere with the health of the surrounding community. The very fine particles in fly ash can be inhaled by humans and cause irritation to the respiratory tract. In addition, fly ash can also pollute water and disrupt the life of aquatic ecosystems (Anwar et al., 2019). Therefore, it is important for the cement industry to pay attention to proper fly ash management, such as by sorting and processing fly ash before it is used as raw material.

Conclusion

The use of fly ash in the cement industry can have significant benefit and environmental impacts, especially in relation to air pollution. Here are some of the prospects that can reduce the environmental impact and maximize the utilization of fly ash in the cement industry: Fly ash has great potential to be used in various industrial applications, including thermal spray coating; Fly ash processing as an effort to reduce air pollution has the potential to open up opportunities for the utilization of fly ash as another raw material, other than for cement production, but fly ash processing is also costly, so it needs to be considered from an economic perspective; Fly ash processing must also be carried out with attention to occupational safety and health aspects, so as not to endanger employees involved in the processing process; The utilization of fly ash waste not only helps reduce the amount of waste generated, but also provides added value economically and environmentally. However, it is necessary to ensure that the utilization of fly ash waste is carried out in accordance with applicable regulations and standards to safeguard human health and the environment; The importance of controlling particulate emissions from coal-fired power plants and developing new clean production-based technologies; Particulate matter emission control technologies, such as combustion modification, electrically enhanced fabric filtration, and new agglomeration approaches, need to be developed in the cement industry; The implementation of fly ash co-processing in cement industry requires a comprehensive approach, covering aspects of technology, regulation, and economic, health and environmental impacts.

Acknowledgments

The author would like to thank my supervisor who has guided me, helped, and provided suggestions for improvement.

Author Contributions

The author is involved in the overall making of this article

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

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