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Impacts of Cement Production on the Environment with Practical Solutions: A critical review

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Abstract

Cement plants aggravate the critical challenges of anthropogenic environmental pollution, global warming, climate change, and excessive fossil fuel use by emitting 15% of global contaminants. These pollutants have a negative effect on ecosystems and human health. Despite the inevitable utilization of cement-based materials in many fields due to population growth and urbanization, addressing this issue is imperative. To reduce the environmental effects resulting from the cement production processes, solutions were introduced, including filtering methods and recycling techniques. Electrostatic precipitators and bag filters are used to prevent emissions from entering the atmosphere. There are many approaches used to minimize the reliance on regular cement, including the use of industrial waste or manufacturing cement-free concrete. For a sustainable environment, it is important to use substitute materials for cement that are both energy-efficient and environmentally friendly in the process of manufacturing concrete.

Index Terms- Bag filter, Cement plants, Electrostatic precipitators, Particulate matter, Polluting materials**.**

1 INTRODUCTION

The development of urban areas and industries in communities generated huge amounts of pollutants in the environment and led to global warming worldwide [1,2]. Without cement, it is impossible to imagine living in the modern world [3]. Cement is widely used in developed countries and is therefore considered as one of the most frequently utilized substances in many construction areas [4,5], applications for decoration [6, 8], and medicine [9, 11]. There are many economic benefits of cement production that enhance job opportunities and improve industrial areas [12,13]. The cement industry faces a number of difficulties stemming from sustainability and environmental concerns, even in spite of its broad appeal and financial success [14,15]. The production of concrete in the world reaches 1 ton for each person annually. Consequently, cement is one of the most significant industrial products in the world because it is the main ingredient in concrete [16,17]. According to data, several countries worldwide produced about 3,600 million metric tons of cement in 2021 [18,19]. According to predictions in Fig 1, the world could consume up to 5800 million metric tons of cement by the year 2050 [19]. Awareness of the adverse impacts of cement and concrete production on the environment is growing significance due to their widespread availability in the global market [20]. A cement factory releases a lot of contaminants into the atmosphere. Additionally, a rise in the output of production or modification in fuel type, fuel consumption, and dust control technologies impacts the contaminant volume and concentration published [21]. Numerous reports and studies have acknowledged that the primary source of particulate matter emissions is the production of cement, which represents 20–30%, or 40%, of the entire industrial release [22]. The emissions to the environment include nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM) [23,24]. Air quality is significantly deteriorated by industrial infrastructure, especially those connected to construction and cement, because they release a high concentration of carbon dioxide (CO_2). Portland cement manufacturing is currently the subject of intense scrutiny [25, 28]. It is estimated that between 5% and 8% of all anthropogenic (CO_2) emissions come from this industrial sector [29, 32]. Consequently, many studies focused on energy issues and carbon dioxide emissions [4], [33, 35]. In the cement sector, dust is released by a variety of operations, including the handling of raw materials, the crushing of limestone, kiln processing, the production and storage of clinker, the grinding of finished cement, and power utilities [23,36]. Several studies have brought attention to the complaints made by locals about air pollution when cement plants are nearby. People who live close to the plant frequently experience confusion and public outcry because of the thick layer of dust that collects on parked vehicles and roads. Unfortunately, a large number of these locals are still ignorant of the possible risks that come with cement dust in their environment, which exposes them on a constant basis to a variety of pollutants that they do not even know the basics about. Many studies have examined the effects that cement plants located in or near residential areas have on the environment. Their studies cover impacts on plants as well as in certain cases, even the aquatic ecosystems, and effects on human health [37,38]. The different kinds of pollutants, their sources of emission, and their effects on people will all be covered in this paper.

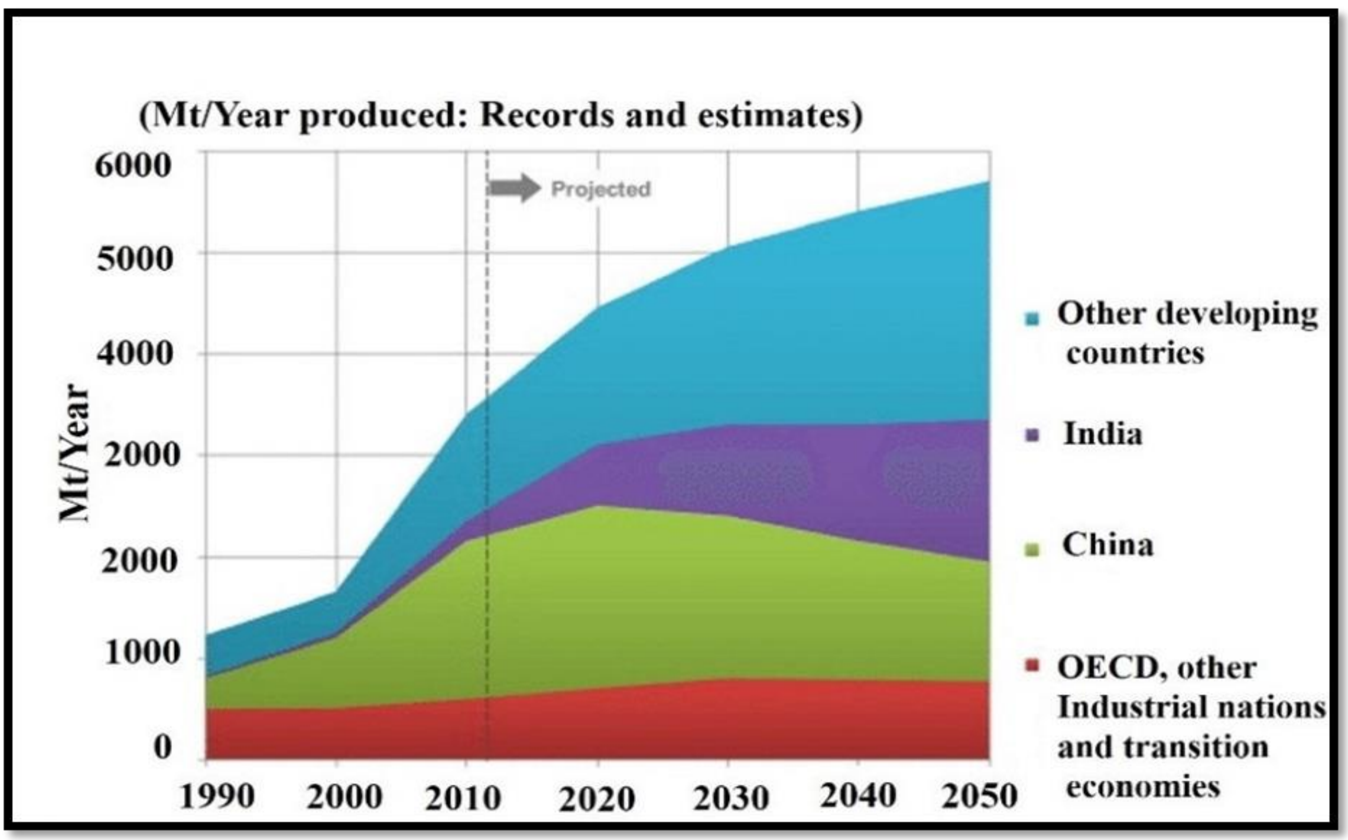

Fig 1. Cement consumption estimates around the world

2 CEMENT PRODUCTION

Raw components utilized to produce cement involve mud, sand, limestone, and shale. These components undergo many processes, such as crushing, grinding, and blinding, as well as other stages shown in Fig 2 [39]. It is necessary to understand the cement production system in order to evaluate the movement of components from the cement company during production steps. From Fig 2 Can be seen that cement production stages are divided into four major steps [40]. Those are

2.1 Quarrying Process (Raw materials)

The extraction of limestone is done by exploding, and silica is extracted by ground flaking. Materials are then transported by dump truck to a loading area, where they are dumped, and then they are transported by dump truck to a crusher and crushing device. Finally, a belt conveyor is used to deliver the materials to the factory [23].

2.2 Raw material preparation process (milling of raw materials and fuels preparations)

The mixing and grinding of extracted raw materials in this stage to achieve an appropriate chemical mixture [39]. This step include:

2.2.1 Grinding raw materials in raw mill

In this step, the raw materials are blended in a specific proportion, then recycled hot air from the furnace room is used to operate in a centrifugal action to maintain a typical temperature of 290 °C. The raw mill consists of three chambers: a drying chamber for using hot air to dry the raw material, compartment I for grinding coarse materials with a ball mill, and compartment II for grinding fine materials with a smaller ball mill (where the ball mill in compartment I is larger than the one in compartment II). The resulting raw mix, which is the material refined by the raw mill, undergoes filtration and enters a separate chamber. The fine material is directed to a mixing silo for a homogenization process, while the residual coarse material is recycled back to compartment II of the raw mill. Homogenizing in the mixing silo is crucial to achieving an appropriate material composition and reducing fluctuations in the quality of the raw mix. This is essential for maintaining kiln performance, as the kiln operation can be disrupted if the materials are not homogeneous [38].

2.2.2 Preparing fuel in a coal mill

Coal will be ground in this step in precisely the same way as it is in the raw mill. In the end, the kiln will receive the finely ground coal and inject it with air via a burner [38].

2.2.3 Burning in kiln

In this stage, the raw mixture is heated to 500 °C. Then, the mixture is transferred to the kiln, where it contains dust and hot gas at a temperature of 330 °C, thereby being directed to the air conditioning tower to reduce the temperature to 120 °C. This process helps in the electrode separation of fines and particles suspended in gas. The raw mixture consisting of (CaO) and (MgO) undergoes several processes in which the temperature of the mixture is raised from 1100 to 1450 °C. During this process, (CO_2) and carbonate compounds are emitted; for this reason, the mixture is cooled by spraying water on it [38].

2.2.4 The final grinding in the cement mill

The clinker temperature must be maintained from 100 to 125 °C in this stage to prevent dry or wet clogging of the cement plant equipment. This can occur due to the accumulation of dust on the equipment or the formation of wet and sticky materials that may adhere to the production equipment. Gypsum and clinker are processed in the mill, divided into two stages: the grinding stage in chamber I and the milling stage in chamber II. In the final stage, the cement is transferred to the separation stage, where the raw material is returned to the mill while the fine cement is stored in the storage silo [38, 40].

2.3 Cement Packaging and Dispatch

In this step, conveyors and bucket elevators are used to move the finished product to storage silos. The majority of cement is shipped in large quantities to clients via trucks, railways, and bags, typically weighting 50 kg each. Most cement is used in concrete as an essential material in the construction industry [38, 40].

There are two types of processes used in cement production: the dry process and the wet process [38].

- **Dry process:** In this process, the raw materials are dried using different types of dryers or air separators, either through the grinding process or before grinding [40].
- **Wet process:** In this process, water is added to the process during grinding [40].

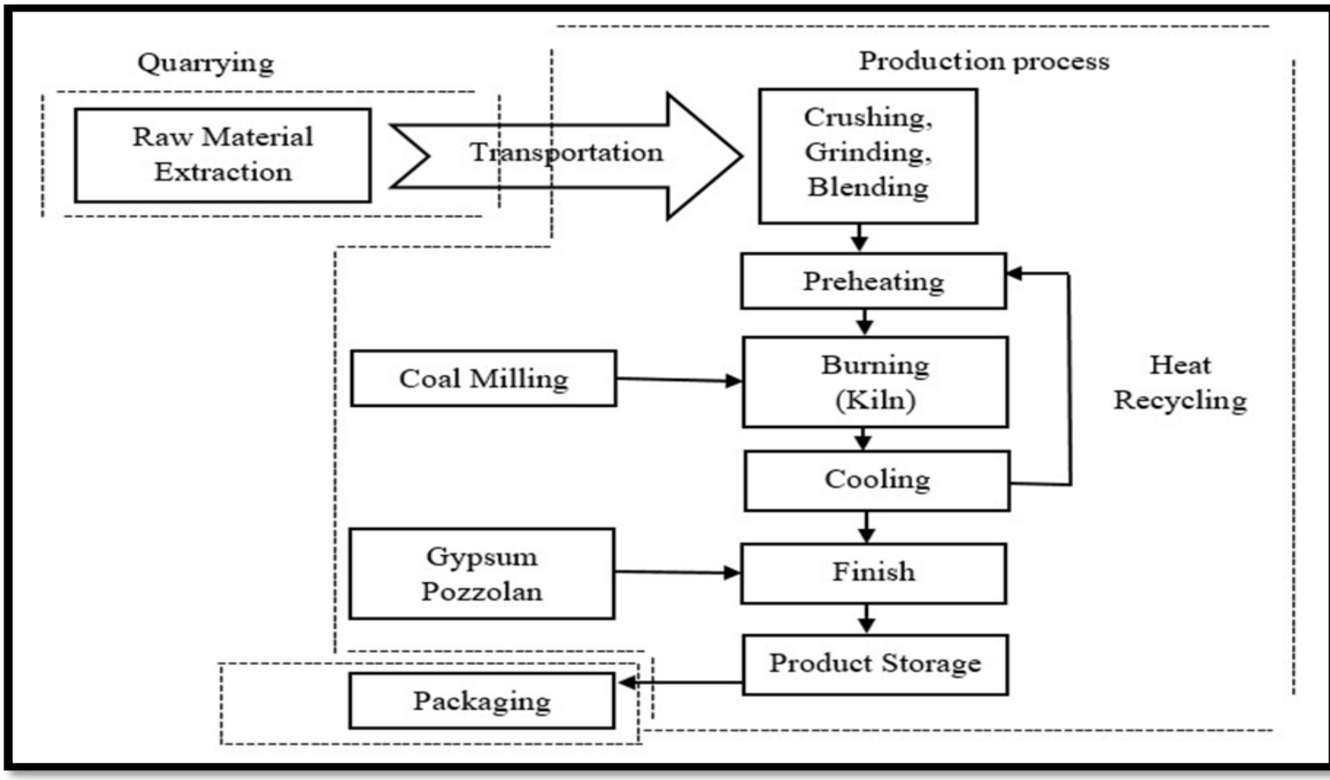

Fig 2. Cement production stages in the cement company

3 TYPES OF POLLUTANTS GENERATED FROM CEMENT PRODUCTION

Polluting materials are released into various media during all stages of production, endangering human health. Humans may be exposed to these harmful effects directly through air inhalation or indirectly through the diffusion of pollutants in soil or water. According to many studies, the most common health problems linked to the pollution of the cement industry are impairments of the respiratory, lymphatic, gastrointestinal, and central nervous systems [41, 44]. Fig 3 illustrates the negative aspects of cement factories, focusing on environmental issues [45].

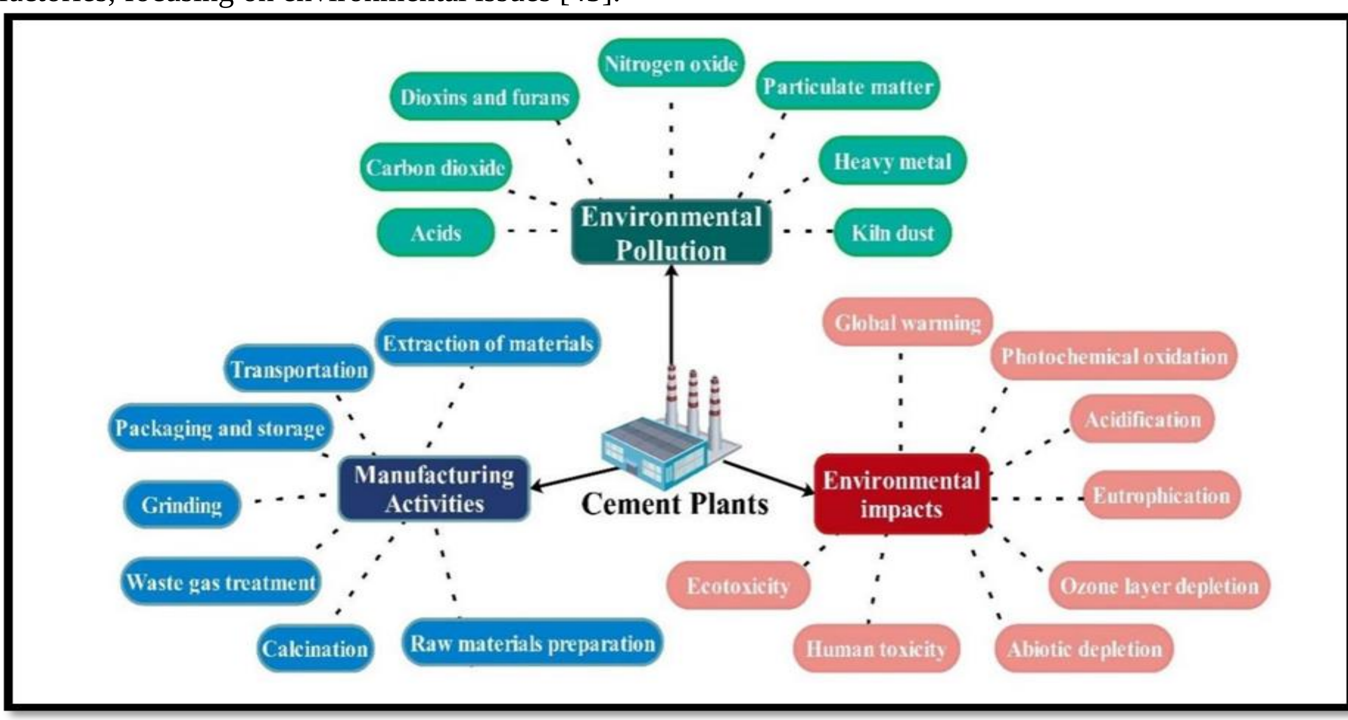

Fig 3. Pollution sources potential from the cement industry

Cement industries release five categories of pollutant materials: solid waste, air emissions, fuel waste, noise pollution, and wastewater [45].

3.1 Solid Waste

Many types of solid waste occur during cement production processes, such as accumulated fly ash, dust, and small rock fragments. The major solid waste collected from the dust filter membrane surface in the cement industry is particulate matter (PM) which is the term for pollutant particles found in materials that have a diameter of 1 to 10 Mm, and alkaline properties (pH~11–12). The manufacture of cement is responsible for 40% of PM emissions, which differ in size and chemical composition depending on the weather condition and source of emissions. The treatment of pollutants becomes more difficult as finer particles form. Therefore, there are two classes of PM: PM_{10} and $PM_{2.5}$, which are attributed to particles smaller than 10 and 2.5 mm, respectively, and the composition of the majority of the PM pollutant. Its high concentration causes the majority of environmental and health problems because of its ability to enter the lungs more deeply. The solid waste content of cement manufacture contains heavy metals caused by the chemical composition of (Al_2O_3) and (Fe_2O_3) [46, 49]. These substances have the ability to damage both biotic and abiotic environmental components. It is necessary to treat the aforementioned waste components in order to prevent them from entering soil, water, or air [49].

3.2 Air Pollutants Emission

Air quality deteriorates, which is considered as one of the major drawbacks associated with cement factories on a global scale. The release of various pollutants, such as dust, sulfur dioxide, nitrogen oxides, ammonia, greenhouse gases, and hydrogen chloride, during the process of cement production contributes significantly to air pollution. The studies mentioned that cement plants annually emit 500000 tons of pollutants, including (SO_2), (NO_x), and (CO), into the atmosphere. To illustrate, dust is produced during packaging and storage stages, as well as by milling equipment and transportation machinery. Furthermore, nitrogen oxides and sulfur dioxide result from kilns through the combustion of fuel, and sulfur compounds found in raw materials, respectively. The release of greenhouse gases into the atmosphere occurs through the heating of calcium carbonate, the combustion of fuels, and limestone preparation [50,51]. The cement industry stands out as the second-most significant contributor to (CO_2) emissions in the industrial sector. The discharge of these pollutants into the atmosphere leads to the occurrence of acid rain, contributes to global warming, poses health risks, diminishes crop yields, and results in a decline in biodiversity. Consequently, the World Health Organization underscores the importance of curbing the release of harmful substances by implementing effective air purification measures [52, 54]. The widely recognized indicator for air quality, known as the Air Quality Index (AQI), is derived from regular assessments conducted on a periodic basis—whether daily, weekly, monthly, or annually. These assessments encompass the measurement of particulate matter (PM), oxides, and greenhouse gases. It is crucial to emphasize that the appropriate AQI is greatly influenced by the geographical location of cement factories and exhibits variations from one area to another [55,56].

3.3 Wastewater

In comparison to other pollutants emitted by cement plants, water waste has garnered the least focus, primarily owing to its minimal usage and limited environmental risks throughout the production process [45]. Water is used in a variety of cement manufacturing processes, including washing and cooling systems. The majority of water is used in operations like compressors, grinding wheels, thermal pipes, kiln bearings, and finishing stages. Water is used concurrently to grind the materials in a feasible contact form. It is also necessary to wash the raw materials prior to processing. Water pollution results from suspended solids, iron and limestone particles getting into the water during the material washing process [57,58]. To remove harmful substances and reuse them in the production cycle, the applied washing water should be neutralized, followed by the sedimentation of suspended waste particles as an environmentally friendly solution. The quality assessment of wastewater in cement industries depends on many indicators, such as pH, biological oxygen demand (BOD), chemical oxygen demand (COD), and total suspended solids (TSS). According to established requirements, the (COD) value should not exceed 250 mg/L, and the BOD/COD ratio should be less than1. Consequently, a reduction in this ratio contributes to fostering a production cycle that is more ecologically sustainable. Moreover, the appropriate pH level for wastewater falls within the range of 6.5 to 9, while the accepted (TSS) standard is below 100 mg/L [59, 61].

3.4 Emissions from Fuel Consumption

The primary factor contributing to the consumption of fossil fuels in the process of cement manufacturing is the essential requirement for energy and thermal treatments. The utilization of fuel is crucial during the thermal treatment phase of calcination and the kiln stage in the production of clinker [46]. The cost of fuel consumption is approximately 30–40% of the overall production cost of cement [62,63]. The combustion of fuel in cement production plants significantly contributes to the release of various gases into the atmosphere, including carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur dioxide (SO_2). Significant amounts of carbon dioxide are released during the calcination process. The calcination process means converting calcium carbonate ($CaCO_3$) into (CaO) and (CO_2) in a rotary kiln at temperatures ranging from 600 to 900 °C in order to produce clinker that acts as a key component of cement [40]. The kiln and drying operations produce oxides of sulfur and nitrogen. The amount of sulfur dioxide (SO_2) produced varies from facility to facility depending on the sulfur compounds found in rocks and burned fuel. Nitrogen oxides (NO_x) are produced during fuel combustion in rotary cement kilns by the combination of nitrogen present in the fuel with the incoming combustion air [64]. Volatile organic compounds (VOCs) discharge into the ambient air from the incomplete combustion of various fuels. Other sources of pollutants also include stored gasoline, solvents, and industrial chemicals. Many factors control the amount of gas emitted, such as the type of fuel, temperature of combustion, content of nitrogen, and sulfur in the fuel [40].

3.5 Noise Pollution

One of the most damaging aspects that is present in any cement plant is the issue of noise pollution. Numerous sources have been shown to play a role in the generation of noise, encompassing gas dynamics, mechanical processes, and electromagnetic activities, resulting in noise levels ranging from 68.8 to 103.3 dBA. Mechanical noises emerge from milling and crusher devices, while gas-dynamic noises emanate from collectors, compressors, and blower operation. Additionally, electromagnetic noises primarily originate from electric motors. Workers in the cement industry face the risk of hearing impairment due to prolonged exposure to noise pollution. Furthermore, extended periods of work in these environments contribute to the development of neurasthenia syndrome, leading to potential health issues such as hypertension, loss of memory, and wakefulness. Consequently, the evaluation of hearing loss caused by noise has been included in the annual health assessments of workers through the implementation of audiometric examinations [65, 67].

Overall, the main pollutants and their sources that are emitted from cement manufacturing can be shown in Fig 4.

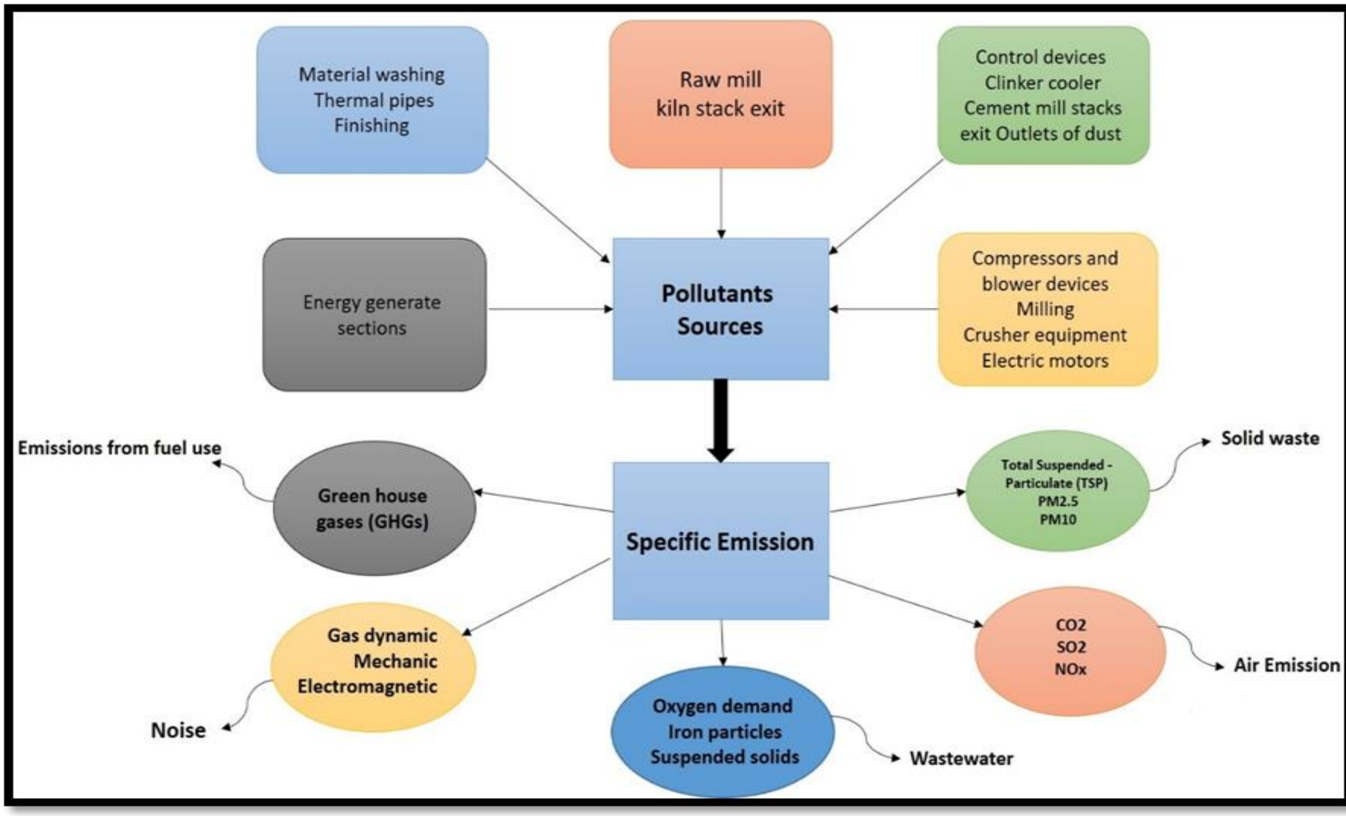

Fig 4. Sources of pollutants in the cement production stages

4 SOLUTIONS FOR MITIGATING POLLUTION IN THE CEMENT SECTOR

Great efforts have been made to reduce the emission of pollutants during the cement production process because they have negative effects on both the environment and human health. It is possible to lessen the dust emission routes by repeatedly applying oil, water, or other soil stabilizing agents. Bag filters (BF) are the most effective way to impede PMs. The process involves feeding the bag filter with dusty air, trapping the pollutant particles with the fibrous network on the filter's surface, and then using a powerful fan to release the clean air. After that, reverse air, pulse jets, or mechanical shakers are used to clean the filtration surfaces [68,69]. Maintaining the bag filters carefully can also help limit dust emissions. Additionally, well-designed and operated electrostatic precipitator (ESP) can reduce dust emissions [70,71]. In this system, a corona discharge applies either a positive or a negative charge to the dust particles, causing a potential difference that allows the particles to settle on the electrode, which is reversely charged. Then, use techniques like washing or dry- eliminating to eliminate the collected particles. The ability of the filter medium to collect particles on the surface of the electrode and eliminate them determines its efficiency, but this ability is directly influenced by the resistivity of the particles, the direction of the gas, and the electrode geometry. One major issue with these filtering systems is that contaminants aggregate on the surfaces of electrodes, weakening the electricity field [72,73]. One of the best approaches to increasing the efficacy of noise management is to make use of technology for insulation, absorption, and reduction of noise [74]. Among the potential strategies for noise reduction are technological and administrative noise control [75]. Administratively, staff undergo a continual rotation process throughout working hours, which involves moving them from noisy to quieter areas to prevent prolonged exposure to noise [76]. Additionally, staff members using earmuffs and earplugs will minimize the noise levels since earmuffs can lower noise by slightly more than 40 dBA to 50 dBA, while earplugs can reduce noise by ± 30 dBA, these practices create a safe environment free from noise for workers in the cement plants [77,78]. It is impossible to ignore the negative effects of oily wastewater on the water system and human health. To solve this issue, various superhydrophobic materials have been employed for separating oil and water [79]. So far, several techniques have been proposed for crafting superhydrophobic products. These include the electrostatic assembly strategy, anodization approach, vapor deposition, hydrothermal treatment, spray procedure, plasma-induced strategy, printing, etching, assembly, aerogel, and condensation response. It is important to emphasize the need for greater efforts in developing these products using methods that are both simple and environmentally friendly while also being cost-effective [80, 94]. Large quantities of (CO_2) emissions result from cement manufacturing processes, especially the combustion of fossil fuels. To achieve low (CO_2) emissions, use alternative fuels and co-production of synthetic fuels [95]. In recent times, geopolymer concrete has gained attention for being produced without the use of cement and demonstrating quicker strength development compared to conventional concrete, making it an attractive choice due to its low impact on the environment. Geopolymer concrete obtains early strength without the need for external heating by utilizing a 5–15% Portland cement substitute. This result in a considerable 20% reduction in (CO_2) emissions compared to emissions from using ordinary Portland cement (OPC) [96, 98]. Furthermore, use waste materials like slag cement, fly ash, and silica to create this type of concrete, which contributes to environmental preservation [99]. In general, it is important to support the production and use of high-quality concrete that uses less cement, adds industrial waste as additional cementitious material, or adopts modern cement-free alternatives like geopolymer concrete in the construction industry in order to protect the environment for future generations [100,101]. Table 1 shows an overview of the methods used to reduce emissions from cement plants.

Table 1. Shows reduction methods for emissions from cement plants

Pollutants	Reduction Methods
Dust	- Repeated application of oil, water, or soil stabilizing agents. - Bag filters: Trap PMs using a fibrous network, clean surfaces using reverse air, pulse jets, or mechanical shakers. - Well-designed electrostatic precipitator (ESP): Applies a charge for dust particles, collects them on electrodes, and eliminates through washing or dry-elimination. - Careful maintenance of bag filters to limit dust emissions.
Noise	- Technological approaches: Insulation, absorption, and noise reduction technology. - Administrative control: Staff rotation to quieter areas, use of earmuffs, and earplugs to reduce noise exposure.
Oily Wastewater	- Use of superhydrophobic materials for oil-water separation. - Techniques include electrostatic assembly, anodization, vapor deposition, hydrothermal treatment, spray procedure, plasma-induced strategy, printing, etching, assembly, aerogel, and condensation response.
CO_2 Emissions (Geopolymer Concrete)	- Geopolymer concrete as an alternative to traditional cement. - Quick strength development without external heating. - 20% reduction in CO_2 emissions compared to ordinary Portland cement (OPC). - Utilizes waste materials like slag cement, fly ash, and silica. - Alternative fuels and co-production of synthetic fuels.

5 CONTROL TECHNIQUES FOR AIR POLLUTION IN CEMENT PLANTS

There are many methods used to reduce air pollution emissions in cement manufacturing. Electrostatic precipitator (ESP) and bag filter (BF) systems are most common to limit the release of pollutants into the atmosphere in cement plants [69]. An electrostatic precipitator (ESP) is a large device used to regulate emissions in industries by collecting and eliminating dust particles, mists, and fumes [102]. ESP units consist of inlets, devices for gas distribution, hoppers, support steel, outlets, and casing for all these parts. The basic principle for operating electrostatic precipitator units in industries is through three main stages: particle charging, transport, and collection. The particles in the flue gas acquire negative and positive charges by passing through negatively charged plates and then positively charged plates, respectively. This leads to the attraction of negatively charged ash particles. The main stages include charging the particles using an applied voltage, transporting them under the influence of an electric field, and collecting them on positively charged plates [102]. This process effectively purifies the air by removing harmful pollutants. The cement industry uses electrostatic precipitation, a highly effective method of eliminating dust and particulate pollutants released from exhaust gases, to reduce emissions [102]. Electrostatic precipitators have many advantages, including efficiently collecting fine dust particles and having an efficiency that can reach over 99.9% in some applications. They function at temperatures between 700°F and 1300°F, with little variation in pressure or temperature. These devices demonstrate stability against extremely acidic compounds by successfully collecting difficult materials like tars and acids. They require less electricity to clean and recover lost products because they retain dry dust. Electrostatic precipitators can also handle high dust flow rates, which improves their range of industrial applications and increases their efficiency [103]. Despite the aforementioned benefits of electrostatic precipitators, they have some disadvantages that make plants choose alternatives to electrostatic precipitators, including: Firstly, their initial cost is significant. It is challenging to collect materials with extremely high or low resistivity. Variable airflow conditions can lead to inefficiencies; however, automatic voltage management can improve collector efficiency. Furthermore, electrostatic precipitators might take up more area because they can be bigger than fabric collectors and cartridge units. They are unable to remove emissions that have a gaseous phase efficiently. Additionally, it could be necessary to utilize a pre-cleaner in order to reduce dust loads prior to the precipitation process [103]. Bag filter (BF) A very essential component of equipment and technology for resolving the issue of smoke and dust released from cement plants is a high-tech dust removal device that can decrease the emission of dust and smoke across a wide range. Bag filters saw significant advancements in the last ten years, coinciding with developments in the steel, concrete, electrical generation, incinerators, and cement industries. Currently, the majority of industries utilize a series of back filters, which are the primary dust-removing devices used to reduce air pollution, particularly (PM_{25}) [104]. Bag filters can work at a temperature of 140–170°C and handle 1,738,000 m^3/h of smoke at a rate of 25–30 g/m^3. The airflow rate is 1.13 m^3/min, the total resistance is less than 2100Pa, and the leakage rate is less than 1.5%. Using 25600 m^2 of fiber, the filter maintained the release density at 10~25 mg/m^3 for 29600 hours, or about 4 years. For these reasons, bag filters achieve a release density to the atmosphere at a rate between 10 and 30 mg/m^3 [105]. The mechanism principle of operating a bag filter depends on many factors, including the screening effects of filter mish that catches dust particles, the inertial impact of dust size, the effect of dust intercept, dust diffusion, and the effect of static electricity [105]. The differences between (ESP) and (BF) systems demonstrated in table 2 determine the suitability of each system for any industrial application. In conclusion, if the application calls for a smaller footprint, works at moderate temperatures, and contains low-moisture dry dust particles, a bag filter can be a good and affordable option. However, an electrostatic precipitator, with its greater capital cost and larger footprint, might be a better choice if the process involves moist contaminants, needs to withstand higher temperatures, and involves larger particle sizes.

Table 2. Comparison between Electrostatic Precipitator and Bag Filter systems

Electrostatic Precipitator (ESP)	Bag Filter (BF)
More emissions than BF	Lower emissions below 10 mg/m^3
Can handle dry and wet pollutants	Not suitable for wet pollutants (only dry pollutants)
Lower pressure drop compared to a BF	Higher pressure drop compared to an ESP.
Can handle emissions in higher temperatures	Can handle emissions in moderate temperatures
Suitable for a wide range of particle sizes (Limited in handling fine particles efficiently)	No limitation on particle size - can handle fine particles
More capital cost than BF	Lower capital cost compared to ESP
Larger footprint than BF	Smaller footprint than an ESP
Not sensitive to corrosive gases	Sensitive to corrosive gases

6 CONCLUSION

The cement industry, integral to modern development, poses significant environmental challenges due to the release of pollutants such as (NO_x), (SO_2), (PM), and (CO_2) throughout its production stages. These emissions have far-reaching consequences, affecting air quality and human health and contributing to global warming. The wide range of pollutants, such as air emissions, wastewater, noise pollution, and solid waste, demand immediate attention and mitigation. To reduce environmental emissions, use either bag filters, electrostatic precipitators, or geopolymer concrete as an alternative material. Choosing an electrostatic precipitator or bag filter system comes after a careful assessment of the unique needs and circumstances of the industrial process, taking into account elements like the type of dust, gas volumes, temperature range, and available space. Emphasizing sustainable practices, such as incorporating industrial waste and minimizing cement usage, is crucial for fostering a more environmentally friendly and responsible cement industry, safeguarding both human health and the planet for future generations.

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