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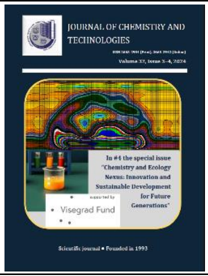

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MINI REVIEW OF TECHNOLOGICAL ADVANCES IN THE PRODUCTION OF PORTLAND CEMENT AND ITS CLINKERS

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Abstract

There was a general agreement among nations to cut carbon dioxide emissions, and many have set goals to cut emissions by 30% to 35% from 2020 levels by 2030. Only the cement and concrete industries release as much as 7 percent of the world's total CO_2 emissions into the atmosphere. The concrete as well as cement industries are fronting concerns about the usage of limestone of cement, designing concrete mixes with an ideal constituents of cement, and enhancing the durability of concrete to promote sustainability. Due to the many benefits of adding limestone to cement, several nations are currently focusing on developing Portland-limestone cement (PLC). Doing so would increase the total volume of cement while decreasing the quantity of clinker needed to generate a specific quantity of cement. A cement plant can save a lot of money, fuel, energy, and natural resources if it can get the clinker factor down. The most important chemical reaction in the process, alite formation, has been significantly improved as a result of technological advancements over the course of the last century. This improvement has been achieved by increasing the homogeneousness of the cement feed in addition to the clinker. By either depressing the reaction free energy of the intermediate compound belite and thereby inhibiting its formation or by depressing the reaction free energy of alite and thereby enhancing its formation, the thermodynamic processes provide a detailed account of this evolution. It is possible to specifically target these processes by adding effective mineralizers, such as fluoride, in a controlled manner. However, the presence of these mineralizers will always depend on the amounts of minor components that are present in the fuels and raw materials utilized. The most important benefit is that it makes it possible to incorporate additional cementitious materials into composite cements without compromising the performance of the cement itself. Because of this, it is possible to produce more clinker while consuming less fuel. This visual review summarizes the pros and cons of using limestone in cement, advancement of Portland cement production as well as its clinker. The impact of limestone on cement's physiochemical characteristics and the role of PLC research in promoting a green economy are briefly reviewed.

Keywords: cement; portland cement; noise pollution; air pollution; water pollution; clinker.

МІНІ-ОГЛЯД ТЕХНОЛОГІЧНИХ ДОСЯГНЕНЬ У ВИРОБНИЦТВІ ПОРТЛАНДЦЕМЕНТУ ТА ЙОГО КЛІНКЕРІВ

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Анотація

Між країнами досягнута згода щодо скорочення викидів вуглекислого газу, і багато з них поставили собі за мету скоротити викиди на 30–35% від рівня 2020 року до 2030 року. Цементна та бетонна промисловість викидають до 7 % світових викидів CO_2 в атмосферу. Через численні переваги додавання вапняку до цементу деякі країни зараз зосереджені на розробці портландцементу з вапняком. Це дозволило б збільшити загальний обсяг цементу, зменшивши кількість клінкеру. Цементний завод може заощадити багато грошей, палива, енергії та природних ресурсів, якщо зможе знизити коефіцієнт клінкеру. Найважливіша хімічна реакція в цьому процесі – утворення аліту – була значно покращена в результаті за рахунок підвищення однорідності цементної шихти на додаток до клінкеру. Термодинамічні процеси дають детальне уявлення про цей процес. Через це можна цілеспрямовано впливати на ці процеси, контрольовано додаючи ефективні мінералізатори, наприклад, фтор. Однак присутність цих мінералізаторів завжди буде залежати від кількості другорядних компонентів, які присутні у використовуваному паливі та сировині. Найважливіша перевага в тому, що це дозволяє включати додаткові цементуючі матеріали в композитні цементи без шкоди для характеристик самого цементу. Завдяки цьому можна виробляти більше клінкеру, споживаючи менше палива. Даний огляд підсумовує плюси і мінуси використання вапняку в цементі, вдосконалення виробництва портландцементу, а також його клінкеру. Коротко розглянуто вплив вапняку на фізико-хімічні характеристики цементу та роль досліджень PLC у просуванні зеленої економіки.

Ключові слова: цемент; портландцемент; шумове забруднення; забруднення повітря; забруднення води; клінкер.

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Introduction

Over the centuries following its 19th-century invention, Portland cement has undergone numerous improvements. In 1824, Joseph Aspdin of England was the first to create Portland cement. The name "Portland" came from the fact that it looked like the fine stone used for construction in Portland, England [1]. In the late 19th century, standards for Portland cement emerged to ensure the consistent production of varying grades and compositions by various companies. As a result, the use of reliable construction methods increased significantly. Chemical analysis and our knowledge of how cement hydrates both advanced throughout the twentieth century, leading to better Portland cement and better performance [2]. This resulted in the creation of various varieties of Portland cement, each tailored to a particular set of needs—Type I, Type II, Type III, etc. Fly ash, slag, limestone, and silica fume are common additives in modern Portland cement. In addition to lowering concrete's environmental impact, these additives can increase the material's strength, durability, and workability [3]. Portland cement production has been the subject of recent innovations aimed at decreasing its carbon footprint

New low-CO_2 cement options, like geopolymer and calcium sulfoaluminate cements, as well as carbon capture and storage (CCS) technology, are examples of recent innovations [4]. Digital technologies are optimizing modern cement manufacturing processes, increasing energy efficiency, and maintaining quality. With an annual production surpassing 4 billion metric tons, Portland cement is by far the most utilized construction material on a global scale. To achieve sustainable development and satisfy the demands of future infrastructure, continuous improvement is essential. Since its creation nearly two centuries ago, Portland cement has experienced considerable improvements in composition, production methods, environmental sustainability, and digital integration. These advancements constantly lead to the development of new building materials and methods [5; 6].

Table 1

Constituents of Clinker

Constituents	Percent present in cement
CaO	62
SiO2	22
Al2O3	7.5
Fe2O3	2.5
MgO	2.5
SO3	1.5

The primary sources of greenhouse gases (GHG) released during the clinkerization process are the calcination of limestone, which accounts for approximately sixty percent of carbon dioxide, and the combustion of fuels, which accounts for approximately forty percent [7]. The cement industry employs the dry process almost universally. The primary objectives of the cement industry are to achieve energy efficiency, reduce the clinker factor, and reduce the carbon dioxide footprint. In an effort to find a solution to this problem, the cement industry is currently manufacturing Portland Slag Cement (PSC), Portland Pozzolana cement (PPC), composite cement, in addition to various blended cements [8]. There was an increase in fly ash and slag utilization, which went from 27 % to 40 % in 2010 and, respectively, to 57 % in 2017. Using blended cements has many advantages, such as lowering greenhouse gas emissions, preserving natural resources, and recycling industrial waste. The three main ingredients in composite cement are portland cement, fly ash, and slag [9].

Table 2

Constituents of Portland Cement Data adopted from [12]

Constituents	Formula	Percentage
Bi calcium Silicate, alite	Ca_2SiO_4 or $2CaO.SiO_2$	25
Tri calcium Silicate, alite	Ca_3SiO_5 or $3CaO.SiO_2$	50
Tetracalcium aluminoferrite, ferrite	$Ca_4Al_2Fe_2O_{10}$ or $4CaO.Al_2O_3.Fe_2O_3$	10
Tricalcium aluminate aluminate	$Ca_3Al_2O_6$ or $3CaO.Al_2O_3$	10
Gypsum	$CaSO_4.2H_2O$	5

The availability of cement-grade limestone is a significant factor in the cement production process. This is due to the fact that this type of limestone is one of the chief constituents that are used to make cement. On average, approximately 1.5 metric tons of limestone are required for every ton of cement that is produced during the production process. Many countries are producing and consuming in a large scale. As an example, India is the second-largest cement-producing country in terms of consumption and production, with a production of 337.32 million metric tons in

2018–19 and an expected demand of 550–600 metric tons by 2025. This demand is expected to be driven by demand in residential, commercial, and industrial construction. As a result, limestone is becoming increasingly scarce due to excessive consumption [10].

At this point in time, it is necessary to create a new clinker as well as cement system design. For example, LC3, reactive belite, geopolymer, Portland Composite Cement, blended cement with a variety of different types of waste (municipal and industrial), in addition to Portland Limestone Cement are all examples of cement systems that incorporate new ingredients [11]. In many cement industry, the manufacture of Portland Composite Cement is portrayed as a cost-effective and environmentally welcoming solution. This is due to the fact that the incorporation of limestone results in a reduction in the manufacture of clinker for a comparable quantity of cement, which in turn results in a reduction in the generation of greenhouse gases [12]. As a result, cement companies are looking into new and improved ways to meet the need for lower emissions. In order to create Portland Limestone Cement (PLC) and lower the clinker content, cement manufacturers are incorporating inter-grinding of limestone, slag, or fly ash into the cement clinker grinding process. When it comes to PLC, European countries have been on top for the past half century. Cement development, on the other hand, began in Germany in 1965; it took over fifty years to get to the point where cement production could use 5 % limestone [13].

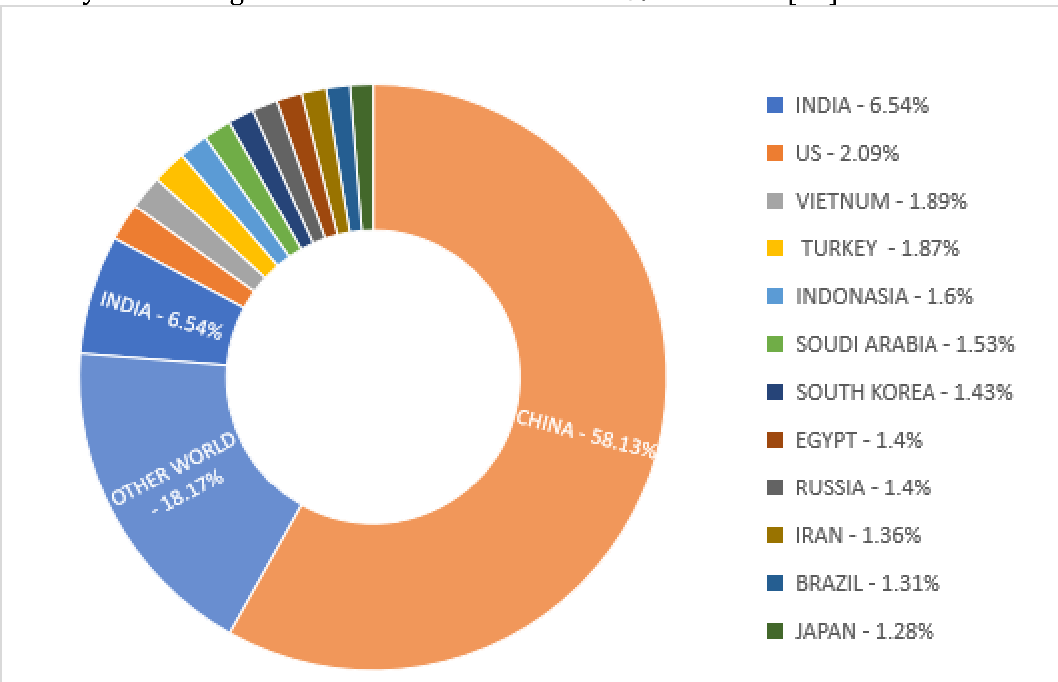

Fig. 1. Worldwide cement production. Data adopted from [12]

Because cement clinker is a mixture of substances that have very similar properties and because it is extremely fine-grained, it is difficult to make quantitative determinations of the optical characteristics of the constituents that make up cement clinker [10]. However, by studying each potential constituent of the clinker separately and determining the specific properties that characterize and differentiate it from other possible constituents, one can overcome this difficulty. Some of the important things that have been done include studying how trace elements affect the formation of alite, how volatiles affect the thermodynamics of clinker production and the smooth running of the kiln, how stable low-temperature mineral assemblages are that come from Klein's phase, and a lot more [12; 13].

American and European countries are producing PLC due to its beneficial effects on energy considerations and enhanced cement properties. India is still in the early stages of PLC development, so this review concentrates on the benefits of transitioning from OPC to PLC, along with the challenges faced thus far and possible solutions [11].

Development of Portland cement

Characteristics of limestone

Minerals that are calcic in nature are the primary constituents of limestones, which are classified as calcareous rocks. There are also detectable amounts of alumina, iron, and alkaline

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oxides in the sample. Typically, these stones are composed of sedimentary rocks that are calcareous and have a medium to coarse grain size. They are extremely hard, compact, and impervious to water and other substances [14]. There is a significant relationship between the specific surface area of the powdered limestone and the characteristics of the concrete product. Mixing limestone and clinker is an integral part of the cement manufacturing process. Compared to clinker, which is an artificial rock mixture consisting of phases such as alite, belite, celite, ferrite, periclase, free lime, and liquid content, limestone, which is a sedimentary rock composed of various forms of CaCO3, is a more pliable substance [15]. Calcite and dolomite are two of the minerals that are typically found in limestone. Calcite has a Mohs hardness of three, while dolomite has a Mohs hardness that ranges from three and a half to four. Therefore, the amount of energy required to grind limestone to achieve the same Blaine fineness is lower than that required to grind other materials [16].

According to Sun et al., the Blaine value can reach 530 m^2/kg and the concrete porosity can reach 14.6 % when the percentage of limestone in the concrete increases to 35 % [17]. When the concentration of limestone increases, the particle size distributions become more fine-grained and dispersed among the particles. Through the process of grinding clinker and limestone together, a wide variety of particle sizes are produced. Through this process, the structure of the hardened cement paste is made denser by filling the spaces between the clinker particles, which in turn reduces the amount of water that is required [18; 19]. In his article, Roy argues that the filler effect and the fineness of the limestone particles both contribute to the acceleration of the cement hydration process [20]. The incorporation of filler results in an increase in the density of the mixture, which in turn allows the mixture to acquire its strength [21; 22]. In comparison, the specific thermal energy consumption for clinker is between 850 and 860 kcal per kilogramme, while the average electrical energy consumption for cement is between 100 and 110 kWh per tonne [23].

limestone's effects on cement's properties

Hydration of cement in the presence of limestone postpones the transformation of ettringite (AFt) to monosulfate (AFm), resulting in the preferred formation of calcium aluminate monocarbonate rather than AFm [24]. At an early age, rapid alite hydration causes a decrease in porosity and an increase in total hydrate phase volume. The water demand is high for particles with narrow size distributions and low for those with wide distributions, says Detwiler [25]. Using limestone, which is soft and has a wide particle size distribution, reduces the water demand. It fills the voids between the clinker particles [26]. Researchers also found that adding finely ground limestone to mass concrete reduces bleeding [26]. The clinker and limestone fineness have a direct correlation with the PLC's setting behaviour [27]. According to reports, cements with less than 5 % limestone had a longer setting time, while cements with more than 5 % limestone had a shorter setting time [28]. Limestone has a catalytic effect on alite hydration (C3S), which releases a lot of heat. Jin used isothermal conduction calorimetry to prove that adding more limestone lowered the hydration rate and total heat released due to hydration [29]. According to Thorne et. al, the incorporation of 25 % limestone into cement paste has a significant influence on the size of calcium hydroxide deposits as well as their distribution [30]. An increase in the hydration of alite was found to be facilitated by the addition of limestone at concentrations of either 5 % or 25 %. This was accomplished by promoting the development of calcium-silicate-hydrate (CSH) rims around the alite grains [31; 32].

The effect of limestone on the mechanical properties of concrete.

Fine grinding would increase the reactivity of Portland cement clinker. At first, the packing effect that limestone provides boosts strength. A 35% increase in limestone addition to PLC would reduce strength; however, this can be remedied by grinding the material more finely [33]. The permeability of the porous material determines how long it will last [34]. The nucleation effect of limestone particles improves the pore structure of cement in PLC. As a result, the permeability and porosity of PLC are even higher than those of Portland cement [35]. The dilution effect of the clinker and the filling property of the limestone affect, and even increase, the overall volume and size distribution of the pores in the concrete [36]. Corrosion is the second critical component. Scientists have shown that PLC-made specimens corrode less quickly than Portland cement-made specimens [37]. Clunkers made with only Portland cement are more susceptible to frost damage than PLC [38]. Cement containing 5 % limestone powder performed better than cement without limestone in chloride resistance tests [39]. It was also discovered that the likelihood of harmful expansions caused by the alkali silica reaction is not increased by using PLC [37].

The Thaumasite Sulfate Attack (TSA), a mineral consisting of calcium silicate, sulfate, and carbonate ($CaSiO_3 \cdot CaCO_3$. $CaSO_4 \cdot 15H_2O$), can deteriorate concrete in the presence of ground or sea water, particularly at temperatures below 5 °C [40]. This gradual reaction causes the concrete to completely dissolve, resulting in a pulpy, white, and soft mass. According to multiple studies, when PLC (<5 % limestone) is used, there is no noticeable negative impact on concrete performance in TSA [36; 38; 40]. However, results vary when using more than 35 % limestone in a PLC. Specimens made with PLC showed less corrosion than those made with Portland cement, according to Bui et al. [37]. Because the carbonation depth of the samples is tiny in PLC-made concrete, they found that it exhibited very little corrosion [41].

Historical developments in clinker chemistry

Portland cement clinker contains five compounds: CaO, $3CaO.SiO_2$, and $3CaO.SiO_2$. $5CaO.3Al_2O_3$. Each of these has undergone extensive research, which we will now consider.

In the middle of the eighteenth century, the Portland cement industry began making hydraulic type of lime at the final stage from argillaceous type of limestone [42]. The primary ingredient of contemporary Portland cement, C_3S, was rarely, if ever, present in products marketed as such by the middle of the nineteenth century [43]. This was due to the fact that the maximum temperatures reached in batch bottle kilns were lower than C_3S's thermodynamic stability limit. Throughout the second half of the nineteenth century, high temperatures were consistently reached, resulting in a product that, despite its somewhat unpredictable chemical composition, bore a striking mineral resemblance to modern Portland cement clinker [44]. A more homogeneous product and a dramatic increase in production capacity resulted from the introduction of the rotary kiln type throughout the twentieth century [45]. Over the past century or two, rotary kiln technology advancements have substantially enhanced fuel efficiency, production capacity, clinker uniformity, and performance [46].

A better knowledge of clinker chemistry has accompanied and aided the advancements in production technology. The first half of the twentieth century established thermodynamics and equilibrium phase relationships, and recent studies have focused on the kinetics of clinkering reactions, the impact of minor components like clinker volatiles, mineralisers, and fluxes. Clinker homogeneity has improved, which is arguably the most notable outcome of industrial expertise and advancements of quality control [47; 48]. Due to the fact that the kiln feed, which was comprised of dehydrated clumps (or bricks) of slurry that were interlayered with the support of fuel coke, was extremely diverse, the clinkers that were produced in batch kilns during the nineteenth century were an equally diverse product [49]. This was made possible by the advent of XRF [50]. In recent years, the implementation of continuous analysis methods that are conducted online has made it possible to further reduce the variability of the raw mix and to make use of a wider variety of alternative raw materials and fuels [51; 52]. Both the degree of diversity of cement plants and the homogeneity of cement (clinker) composition in all of them have increased over the last few years [53].

Clinker chemistry: trends and future development

As mentioned above, the progress in clinker production over the years has led to increased production, reduced fuel consumption and reduced emissions (including dust, sulfur dioxide, nitrogen oxides, carbon dioxide, and so on) [54]. In addition, we observed that the compositions of raw materials and clinker became much more homogeneous, resulting in improved cement consistency and superior cement quality [55]. Most cement manufacturers have concluded that a clinker consisting of 58–64 % C_3S and about 22% C_3A and C_4AF is the most effective combination to achieve good overall performance [56]. Although there are a few remarkable exemptions, such as small alkali substances for little alkali cements and little C_3A for sulfate resistance, the majority of cement manufacturers do not target clinkers for specific applications [57; 58]. Instead, supplementary cementitious materials (SCMs) are mainly used to achieve the desired cement properties for specific applications. Most recent technological advancements in clinker production, instead of focusing on improving clinker chemistry, aim to increase kiln efficiency to reduce specific CO_2 emissions and other pollutants like heavy metals and NOx [59]. Systems that make the most of alternative fuels, such as biomass, have also been improved [60]. Grey laid the groundwork by demonstrating that this method can produce clinker with comparable cement performance [61]. It goes without saying that it is essential to take into consideration the

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extent to which modified processes and fuels introduce minute components that have an effect on the chemistry of clinker and the performance of cement [58]. Meat and bone meal, which is rich in phosphorus, and fuels derived from refuse, which are rich in chlorides, are the two types of biofuels that are currently being used the most, at least in Europe [54]. On account of the fact that phosphorus does not demonstrate a strong preference for one silicate phase over the other, its influence on thermodynamics is relatively minor. Through the process of replacing silicon in both alite and belite, it does, however, result in an increase in the modal content of belite. Additionally, the clinker contains phosphorus at a level of approximately 1 %. Contrary to what most people believe, thermodynamic stabilization of belite is not achieved, and any increase in the amount of belite present can easily be countered by increasing the amount of calcium present in the clinker [54; 36].

However, chloride does favor alite, and end-member phases like alinite only emerge at very high concentrations [62]. Similar to the action of fluorine, this reduces the free energy of alite, which improves the clinker burn ability or, to put it another way, allows a higher alite content to be achieved at the same clinkering temperature. Obviously, the embedded steel reinforcement poses a corrosion risk and precludes its usage in general-purpose clinkers [52]. However, this could offer a way to create a low-energy clinker specifically for non-reinforced concrete. This would also enable the use of fuels rich in chloride more frequently, such as fuels derived from refuse, which typically contain around 50% biomass but have limited use due to their chloride content [62].

Environmental impact and modification of cement production

Resolution of Air pollution

The process of making cement releases a significant amount of dust into the air. Several processes, such as transportation, loading, and unloading of clinker from the silo, trigger this phenomenon [54]. Among the many greenhouse gases that contribute to the warming of the planet, carbon dioxide (CO_2) ranks highly. The formation of CaO in cement production releases CO_2 and water vapor at very high temperatures. It uses between five and seven percent of the world's energy, which results in five to seven percent of CO_2 emissions; carbon dioxide makes up sixty-five percent of all greenhouse gases [55].

The IPCC's Fifth Assessment Report found that the manufacturing of materials accounts for the majority of industrial COE emissions. Of all CO_2 emissions, 84 % come from just three industries: transportation, power generation and distribution, and manufacturing. Cement production accounts for 12 % to 15 % of all industrial energy consumption, depending on the method and resources used [56]. Furthermore, research reveals that cement manufacturing accounts for 5–8 % of the CO_2 emissions. In 2011, cement production around the world produced 4.1 metric tons of CO_2. Such massive CO_2 emissions could thus render anthropogenic climate change inevitable [57]. Furthermore, the cement manufacturing process, from extraction to packing and loading, releases particulate matter, including PM10 and PM2. 5. The cement industry also released 136 metric tons of nitrogen oxides, 4,833 metric tons of sulfur dioxide, 183 metric tons of volatile organic compounds (VOCs), including harmful dioxins, furans, and PCBs, and 320 kilograms of mercury in 2020 [58]. Conversely, every tonne of Portland cement clinker releases 1.5 to 10 kg of nitrogen oxides into the atmosphere, resulting in approximately one tonne of greenhouse gas per tonne of Portland cement [59]. Burning fossil fuels, nitric acid, and biomass produces Nitrous oxide (NOx), a potent greenhouse gas. Furthermore, the emission of dust and other polluting gases diminishes the air quality, thereby impacting the healthy lifestyles of people worldwide [60]. Workers, for example, are more likely to suffer from chronic obstructive pulmonary disease (COPD) and other respiratory issues due to the integration of PMs of varying sizes [61].

Research on PM's impact on the respiratory system has shown that, because of their slightly smaller size, PM10 and smaller particles are able to penetrate the respiratory tract [62]. As the average age of construction workers continues to rise, it becomes more clear that those with known cardiopulmonary conditions and the elderly are among the most vulnerable populations when it comes to exposure to PM2.5. As a result of long-term exposure to PM, approximately 4,000 people die prematurely in Beijing each year, with lung cancer accounting for 20 % of those cases [55]. Additionally, volatile organic compounds (VOCs) can pollute soil and groundwater, and they are also precursors to ozone formation. Research has shown that volatile organic compounds (VOCs) can stunt the growth of large-leaved plants as well as cause chlorosis and necrosis. Respiratory and eye irritation, fever, nausea, kidney, liver, and central nervous system injuries are all possible

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side effects of volatile organic compounds (VOCs) [61].

Since it became apparent that the cement industry was having a detrimental impact on both the environment and people, there has been a consistent concerted effort to reduce the amount of pollution that is produced by industrial processes. According to Stajanca, dust emission pathways can be reduced by repeatedly spraying soil stabilization materials (such as water or oil). Additionally, dust emissions can be reduced by carefully maintaining baghouse filters. Another benefit of ESPs that are well-designed and operated is that they reduce the amount of dust emissions [62].

Water and noise pollution

Dust pollution, which can lower visibility and air quality, is another by-product of the cement manufacturing process. The CDC explicitly states that drained dust can contaminate water, potentially harming human or animal health [63]. Wastewater runoff, when released into the atmosphere, pollutes rivers and groundwater sources. Human activities, such as population growth, building, and urbanization, contribute to soil degradation in certain regions. Poor land management is one of the causes of soil erosion, which puts the soil at risk and causes water to run off the landscape rather than infiltrate properly. In addition, the majority of the noise emissions are caused by the process of manufacturing cement. Heavy machinery, the burning of clinker, the storage of materials, and the preparation of raw materials were all factors that contributed to noise pollution [64]. In noise processing, industrial noise is divided into three main categories: complex gas noise, electromagnetic noise, and mechanical noise. These three categories are at the core of the noise classification system. The primary sources of noise in cement plants are the following: gas-dynamic noise, which is caused by the activity of blowers; mechanical noise from milling machines and crushers; and electromagnetic noise from electric engines [65]. Human hearing is not the only organ that is negatively affected by noise pollution; the nervous system, digestive system, and cardiovascular system are also profoundly affected.

Memory loss, hypertension, insomnia, vertigo, headache, and exhaustion are symptoms of neurasthenia syndrome, which is more common in people who work in environments with high levels of noise, such as cement plants. The general public now believes that exposure to loud noises from vehicles and factories increases the likelihood of cardiovascular disease. In addition, the noise pollution that the cement plant employees face during their workday makes it difficult for them to detect any potential danger signals, which in turn affects their safety. Figure 1 provides a high-level overview of the effects on cement production [65].

Technologies that attenuate, absorb, and insulate noise are some of the most effective ways to improve noise control efficiency. Technical, administrative, and receiver-specific noise management are all potential avenues for reducing background noise. Rotating employees from noisy to quieter areas is a good administrative practice that could reduce their exposure to noise. In addition, the receiver's noise reduction features guarantee that the obtained noise level is lower than what it would be with the staff wearing earplugs and earmuffs. Earplugs can reduce noise by approximately 30 dBA, while earmuffs can lower it by around 40 dBA to 50 dBA [66]. This means the operator's noise sensitivity is about right. Meanwhile, the Standard Operating Procedure (SOP) in the factory was an integral part of the ear protection devices offered by the company [65].

Beyond that, oily wastewater has significantly impacted the condition of the water system. The use of various super hydrophobic materials for oil-water separation has been an approach to this problem. Electrostatic assembly, condensation response, anodization, hydrothermal treatment, printing, vapor deposition, assembly, spray process, aerogel, etching, and plasma-induced strategy are some of the different ways that super hydrophobic materials have been made so far [67]. It should be emphasized that there needs to be a greater push to make the desired products in an easy, cheap, and environmentally conscious way [68].

To reduce the need for non-renewable resource consumption in energy generation, the cement manufacturing sector can make use of recycled materials such as rubber, sludge, waste oil, and waste fuel as renewable fuel [69]. Researchers are exploring the potential of using waste material as a partial cement replacement in concrete, and exploring methods to enhance the eco-friendliness of cement plant operations [70]. Interest in more conservative and cost-effective concrete materials has increased due to growing concerns about the environmental damage caused by the cement industry, as pointed out by Chowdhury et al [71]. In an effort to lessen reliance on limestone, research into potential alternatives to cement, such as waste materials like oyster, cockle, and eggshells, has begun [72].

The pozzolanicity of industrial by-products like fly ash, slag, palm oil fuel ash, rice husk ash, and waste ceramic powder has led to their use as an additional cementitious material [73]. Geopolymer concrete, a more eco-friendly alternative to traditional concrete, has recently gained popularity due to its ability to increase strength more quickly and its lack of cement use [69; 72]. With a 5–15 % Portland cement substitute, geopolymer concrete can reach early strength without the use of external heat, resulting in 20 % less CO_2 pollution compared to OPC [73–76]. Furthermore, this concrete can be made by combining various waste materials, such as fly ash, slag cement, and silica, which helps to create an even greener environment [77]. One can recommend the construction industry to use modern free cement concrete, such as geopolymer concrete or concrete with a lower cement content, and add industrial waste as an additional cementitious material to preserve the natural environment for future generations [78; 79].

Conclusion

Since the 1960s, limestone cements have found widespread use across the globe. The Indian cement industry is highly interested in PLC development for a number of reasons, including the possibility of improved concrete performance and environmental sustainability. Among the many advantages of PLC are the following: (a) lessening the clinker factor of cement, which in turn lowers emissions of greenhouse gases; (b) making the cement more workable; and (d) requiring less energy to produce the cement. Adding limestone to Portland limestone cement makes it easier to grind, reduces the amount of water needed, increases strength, and reduces bleeding in concrete. The reactive properties of limestone allow it to serve as a heat-reduction agent and a nucleation site for clinker hydration products. Particle size distribution, grinding method (intergrinding vs. separate grinding), and limestone quality all have an impact on PLC performance. The cement industry hopes to reduce greenhouse gas emissions by adopting the PLC development process, an energy-efficient technology. This is because the cement manufacturing process uses less clinker, electrical, and thermal energy, which in turn minimizes CO_2.

Because of advancements in manufacturing technology and clinker homogeneity, there have been significant improvements in production output, fuel consumption, and product performance. These improvements have been brought about by the homogeneity of the clinker. Due to this advancement, the formation of alite, also known as C_3S, has been significantly improved. Components that are preferentially incorporated in alite, such as fluorine, magnesium, zinc, copper, and so on, have the ability to either promote the mineralization of alite or limit the mineralization of belite, which would allow for further advancements in this direction. Within the context of circumstances in which higher strengths are not required, this can be utilized to reduce the amount of clinker that is present in composite cements while preserving the same level of strength. In response to calls to reduce CO_2 emissions by lowering clinker contents without affecting the performance of cement and concrete, it is likely that new clinkers are being produced and that a greater emphasis is being placed on clinkers with a high concentration of carbon with sulphur (C_3S).

Conflict of interest

Authors declare no conflict of interest.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

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