

Cement industry – Associated emissions, environmental issues and measures for the control of the emissions

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This article contributes to:



Highlights:

- The cement industry releases emissions that engenders imbalance in the ecosystem and public health.
- The chief air pollutants are the inorganic gaseous emissions (carbon dioxide (CO₂), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur SO₂), particulates of various size ranges and elemental emissions.
- Exploitation and processing of cement must be done in a sustainable manner to prevent damage to the environment.
- Properly control and management are needed to minimize or curtail the attendant emission to the environment

Abstract

The cement industry though the backbone of modern construction and civilization is associated with the emission of diverse atmospheric pollutants with numerous attendant effects on the balance of ecosystem, human and environmental health, and the global climate in general. Despite the huge advantages derivable from the industry, exploitation and processing of cement must be done in a sustainable manner to prevent irreversible damage to human, animal and vegetation health as well as the environment. Research papers were reviewed from different databases like ScienceDirect, ResearchGate, Google scholar, and Scopus the chief air pollutants are the inorganic gaseous emissions (carbon dioxide (CO₂), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur SO₂), particulates of various size ranges and elemental emissions. The present study carries out holistic review of the cement production process with a view to identifying the principal air pollutants, sources and associated environmental issues. The study also reviews the pollution control measures currently in use and calls for a concerted effort from researchers, industry operators and regulators at working to reduce emissions with a view to upholding environmental sustainability.

Keywords: Cement industry, Pollutants, Separation processes, Sustainability, Global warming

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1. Introduction

The role of cement in modern society cannot be over emphasized. It is an important material in the construction of bridges, roads, dams, houses, etc. The cement industry is one of the manufacturing industries that impact directly on the economy of nations in terms of income generation and massive employment for the citizenry [1]. Also, there is presently no close substitute that can replace cement as a binder; its usage in the construction industry is massive. It is a commodity in demand, second only to water [2].

Cement powder is made from calcined lime and clay and serves to bind materials via chemical means. It can be hydraulic or non-hydraulic. The hydraulic type is sticky with water because of the chemical reaction of the dry powder with water. It is safer to use in water due to its solubility and hardening property. Hydraulic cements set in wet condition and protect the applied surface against chemical attacks. Example of this type of cement is the Portland cement [2]. The non-hydraulic types (gypsum, lime and oxychloride) do not harden with water. They are therefore vulnerable to chemicals and are not reliable as the hydraulic types which are commonly used. The non-hydraulic cements are used in dry conditions for brick, mortar and stonework [3]. Cements generally are basic components of concrete used in construction. For every human, 1 tonne of concrete is manufactured per year [4].

As countries develop, the demand for cements rises due to growth in population and urbanization. There would be need for shelter (in housing, health care, education, or workplaces), construction of infrastructure (dams, irrigation systems, etc. to cater for human activities [5]. Demand for cement can be a result of construction of residential or non-residential purposes, either government or private. For non-residential purposes, there can be flaws and repetition of construction which can lead to more demand for cement until such construction meets the required design intention. The residential purpose holds a higher demand for cement compared to non-residential ones since population increase, with people wanting a place to live in [6]. Wastes emitted from cement industries contribute to their demand since they are less energy intensive and emit lesser CO₂ to the atmospheres compared to other alternative construction materials as steel or wood [7].

As cements seem to be very important in value, it still poses adverse effect to the environment in form of emission of pollutants [8], [9]. The pollutants are in form of gas, liquid and solid. There comes the necessity to understand the impacts on environment and the separation processes for the control of pollutants in the cement industry. Separation process involves separating components from another a mixture by passing one phase over another [10]. The phases could be gas -liquid, gas-solid, liquid-liquid or liquid-solid in combination. The core pollutants from this industry are carbon (IV) oxide nitrogen oxides, sulphur (IV) oxide and grey dust [11], [12]. These lead to poor air quality which affects the health. Poor solid or liquid wastes disposal from cement industry can lead to land and water pollution. According to Air Quality Resources [13], the cement industry contributes to five percent of the gases that cause global warming.

Environmental pollution according to [14], [15] is the addition of unwanted chemical or biological materials to the earth, thereby affecting the normality of the ecosystem or environmental as a whole. So, pollutants from cement industry leads to air pollution during combustion of raw materials forming clinkers or quarrying process. The gaseous pollutant released, pollutes the air to impair the air quality [16], [17]. Water is polluted during the discharge of organic sludge or leakages which come in contact with water bodies, hence killing plants and animals in waters [18]. These pollutants have been on the increase from cement industry as a result of improving the state of the economy via or urbanization.

No doubt, environmental pollution from the cement industry, from the feeding to the refining processes, distorts the ecosystem hence these processes need to be properly controlled and managed to minimize the emission of pollutants to the environment. The equipment employed along the floor of cement production always include equipment for pollutant removal and minimization. Hence, this article has put together the processes used in controlling pollutants in cement industry for the use of producers and for further research by researchers.

2. Methodology

This review paper was prepared considering modern protocols for review and literatures from diverse authors. Research papers were reviewed from different databases like ScienceDirect, ResearchGate, Google scholar, and Scopus. Terminologies used in the course of the search are cement, sustainability, pollution control, pollutants, waste management, global warming. Published documents including the report from the European Emissions Trading Scheme (EU ETS) were included with the unpublished ones exempted. The search covers review papers like the term papers, journals and conferences all based in English. The searches cover work from the year 2000 to 2021. The authors conducted an initial analysis of the literature obtained from the keyword search. From analysis, it was determined that the pieces of literature could be divided into three groups based on the scope of their contents. Since the authors focused more on literature related to cement industry. The articles were divided into: manufacturing, pollutants emitted, environmental issues and pollution control and management.

3. Results and Discussion

3.1. Cement industry

The processes involved in cement manufacture according to various authors are quarrying, preparation of raw materials, pyro- processing, cement grinding, packaging with transportation. According to Alabi [19], the processes are as described:

- a. **Quarrying:** Based on research, it was in agreement that the raw materials (silica, alumina, lime and iron) for the cement are obtained from the ground via quarrying and mining. Limestone (CaCO_3) is the chief raw material and the quarrying process and the quarrying processes comprises drilling, blasting, excavating, handling, loading, hauling, crushing, screening, stockpiling, and storing.
- b. **Preparation of raw materials:** In raw milling, the raw materials obtained are mixed to achieve the standard chemical compositions. This is then grinded to suitable size to give the best fuel performance ratio and strength. The grinding is done in a cement kiln. The processes in the preparation of raw materials can be categorized into the dry, wet and semi-dry stages.
 - *Dry stage:* Prior to grinding, the raw materials are dried in dryers (such as impact, drum or paddle-equipped rapid dryers) or air separator.
 - *Wet stage:* When grinding the raw materials in the cement kiln of cylindrical shape, water is fed with the materials.
 - *Semi-dry stage:* The raw materials are produced in pellets in a lepol kiln in presence of water, allowed to dry and preheated by the moving grate.
- c. **Pyro-processing:** Here, heat is applied to the mix of the raw materials to give clinkers of hard, grey, spherical buds of about 0.32-0.5 cm.
Pyro-processing involves drying, calcinating and sintering. The mix is delivered as dry powder, slurry or moist pellets. The pyro-processing occur in the rotary kiln or sometimes outside the kiln on moving rates supplied with hot kiln gases.
- d. **Cement grinding:** After the pyro-process with kiln, cement as clinker is grinded into smaller and smoother forms. Gypsum is then added to control the setting time of cement (time at which the cement loses its plasticity). Without gypsum, the clinker as cement condenses in presence of water, hence gives out heat [20], [21].
- e. **Packaging with transportation:** The now finished products after grinding can be stored in silos. The storage is done by moving these finished products in conveyors and bucket elevators. The packaged cements reach the consumers in numbers, standard weight of 50 kg per bag through rail networks or large trucks.

3.2. Pollutants emitted from cement industry

The pollutants from the cement industry can be classified in terms of solid, liquid or gaseous, causing soil, water, air or noise pollution [22]. Though the cement industry rarely releases liquid pollutants, these are seen as effluents from the manufacturing process.

- a. **Solid pollutants:** These are wastes from the clinker production which are the materials that do not meet the required standards, hence are removed from raw materials during the preparation of the raw mill [23]. Examples of the solid wastes include spoil rocks, fly ash or kiln ash, plastics, coke and metal scraps.
- b. **Gaseous pollutants:** Gaseous pollutants include particulate matters, nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon oxides (CO and CO_2), volatile organic compounds (VOCs), dioxin and furan and metals with their compounds [24]. They are expatiated below:
 - *Particulate matters:* Activities such as quarrying, hauling, crushing, grinding of raw material and clinker, fuel preparation, clinker grinding and cement packing in the cement manufacturing process result to the emission of particulate matters to the atmosphere. Particulate matter is consisting of fine particles that can remain suspended in the air which include dust, soot, and liquid droplets.
 - *Carbon oxides (CO_x):* During calcination of limestone, CaCO_3 , carbon (IV) oxide is released with calcium oxide as product. Burning of fuel in kiln leaves carbon (IV) oxide as by-product. As stated from [24], half of CO_2 is obtained from decarbonization of raw material with another half from combustion of fuels. CO_2 can be in form of coal, fuel oil, alternative fuel or pet coke.
 - *Volatile organic compounds (VOCs):* VOCs are obtained from partial combustion and organic matter in the raw materials for cement production.
 - *Dioxins and furans:* Dioxins and furans come from combustion of fuel in addition of chlorine and organic compounds, though cement manufacture is scarcely a root for the release of dioxins and furans.
 - *Nitrogen oxides (NO_x):* Nitrogen oxides are obtained when combustion flames from the rotary kilns react with the gases in the atmosphere. Thermal oxidation occurs between 1200 – 1600 °C. Nitrogen oxide generation increases with increase in temperature. According to

Mishra and Siddiqui [24], 90% of nitrogen oxides are in form of nitric oxide and 10% form nitrogen dioxide.

- **Metals and their compounds:** Metals and compounds are emitted during combustion of gases and raw materials in clinker coolers. The emissions vary in relation to the concentration of these metals in the raw materials, fuel types and gases in the air. The metals emitted are zinc, cadmium, arsenic, thallium, lead, mercury and lead, all in minute proportion.
 - **Sulphur oxides (SO_x):** Sulphur oxides come a result of burning of fuels which contain sulphur and oxidation of sulphur present in the raw materials. Sulphur in the raw materials is oxidized to form SO₂ and SO₃ at heating point between 370° C and 420° C in the kiln preheater. SO₂ is formed by thermal decomposition of calcium sulphate in clinker. SO₃ is quickly decomposed to SO₂ and O₂.
- c. **Noise pollutants:** These pollutants come from air flow and machineries used in the process of cement production. Noise from air flow is as result of air at speed of 15 to 20 metre per second moving through chimneys, tube or ducts. These channels vary the rate of sound at different velocity or cross-section. Noise from machineries come from process equipment like fans, compressors, heaters, pumps, crushers, kilns etc [24].

3.3. Environmental issues

The environmental issues that are associated with the running of cement industry are those posed by the pollutants emitted as reported by Alabi [19].

- a. **Particulate matter:** Reduces visibility and the purity of air in the environment become less. Water bodies become contaminates when the matter in dust particles get washed in. The rate at which plant grows also decreases. Toxic metals and compounds such as: chromium, lead, barium and nickel make up particulate matters. Inhalation of these compounds lead to ill effect in health such as cardiovascular and respiratory diseases. Irritations to the eye, skin and throat are other ill effects of particulate matter.
- b. **Carbon oxides (CO_x):** Carbon (II) oxide, CO and carbon (IV) oxides, CO₂ are example of carbon oxides. The CO₂ gives climate change if released to the environment. With continuous release temperatures increase, hence leading to drought in affected area, horrid conditions of weather, unbalance in the ecosystem and this affect the health of livelihood. CO₂ is released from the calcination of calcium carbonate to produce cement in the rotary kiln. CO also affect the health of people in a negative way such that oxygen supply to the body system becomes shortened. CO leads to smog to cause difficulty in breathing.
- c. **Volatile organic compounds (VOCs):** The volatile compounds degrade the soil and ground water. VOCs can cause retardation of plant growth, yellowing of leaves and death in tissues and cells of plants. Exposure to the VOCs lead to goosebumps in respiratory tract and eyes, headache, nausea, liver failure, kidney and central nervous system.
- d. **Dioxins and furans:** These pollutants lead to liver damage, reduction in weight, skin irritation, weak immunity, slow development of reproduction organs.
- e. **Nitrogen oxides (NO_x):** Nitrogen oxides group consisting of nitric oxides, nitrogen dioxide, nitric acid, nitrates and nitrous oxide. This group in presence of compounds of acid turns the water bodies into acidic form, thereby ruining the habitation of the living things in the waters. Smog is formed when NO_x with volatile compounds in sunlight undergo chemical change with the atmosphere, making breathing unbearable in ill-health. In nitrogen dioxides, lungs seem to witness changes. Lungs increase in size even prematurely.
- f. **Metals and their compounds:** They make plant cell structure behave anomaly. Heavy metal in high amount endangers aquatic and terrestrial life. Metals damage brain and nervous system, high blood pressure, failure of gastrointestinal and reproductive abilities.
- g. **Sulphur oxides (SO_x):** The sulphur oxides cause acid rain when it reacts with water vapour and chemicals in the atmosphere in presence of sunlight. The combination of this reaction forms sulphuric acids which come in form of rain to damage lives and properties. Agricultural products and life of plants suffer severe damage with high level of sulphur oxides released to the atmosphere [19].
- h. **Noise pollutants:** Noise pollutants either from the machineries or air ducts can lead to partial deafness in hearing or even total when the level of sound is too much and occur at prolong duration. So much noise could also cause headache or migraine.

3.4. Pollution control through separation process

Different authors have looked into various ways in tackling these pollutants emitted to the atmosphere, the following ways were taken:

- a. **Adsorption with the help of carbon:** According to [24], when dust from exhaust gases is passed through bed composed of active carbons, sulphur oxides, nitrogen oxides, VOCs, heavy metals and dioxins/furans are adsorbed. With these pollutants adsorbed, clean gases are then emitted to the atmosphere. The active carbons are removed, preserved in silos, separated and restored with another adsorbent; VOCs are removed from the gases and burned.
- b. **Application of low NO_x burners:** Low NO_x burners are used to lower the NO_x gathering in the atmosphere during combustion of fuel. With these burners, NO_x formation due to high temperature is prevented also NO_x resulting from oxidation of nitrogen-filled fuel is prevented also. Low NO_x burners lower the gathering of NO_x by 60 percent.
- c. **Capture and storage of carbon:** Carbons in form of carbon (IV) oxides are separated from exhaust gases due to combustion, these oxides are separated, pressurized, transported with the aid of pipelines and finally stored [25]. Dunuweera & Rajapakse [25], outlined few processes in capturing and storing carbon which are:
 - *Calera process:* Scrubber liquid (water with high pH containing chlorine, magnesium, calcium, sodium, hydroxide) in scrubber captures the CO₂ and converts this carbonate. The carbonates can be magnesium or calcium carbonate which can then be filtered, washed and dried. The dried carbonates are fed back into the kiln as fresh material to produce cement. It has been reviewed that seawater to form part of the scrubbing liquid.
 - *Oxy-combustion:* Fuel is burnt in pure oxygen rather than air. The rate at which fuel is consumed is reduced when there is no nitrogen gas to burn and only pure oxygen involved. With this process used, higher amount of CO₂ (80%) can be recovered with Calera process.
 - *Cryogenic distillation:* The process of separating gases apart from CO₂ and N₂ at low temperature, CO₂ will be trapped liquid form and N₂ will remain as vapour. N₂ gas is then goes upward of the chamber through the outlet and the trapped liquid is collected at the downward part of the chamber. Refrigeration can be used in place of cryogenic distillation but it operates at higher pressures and lower temperatures. The Cryogenic distillation is a more reliable process than other separation processes to capture CO₂ because CO₂ purity is high (that is 99.95 percent above).
 - *Membrane process:* In this process, appropriate membranes can be used to separate or adsorb CO₂ in the kiln exhaust gas. Membranes like the Poly (methoxy ethoxy) ethanol phosphazene (MEEP) hollow fibre membranes are very good CO₂ separation and storing membranes – (methoxy ethoxy) ethanol groups bonded P have strong interactions with CO₂. CO₂-selective membranes used are polymer blends with strong connection with CO₂. Mondal and Mandal, cited by Dunuweera & Rajapakse [25], reported cross-linked thin-film composite of polyvinyl alcohol (PVA)/polyvinylpyrrolidone (PVP) blend with amine carriers as a good example of CO₂-selective membranes.
- d. **Electrostatic precipitators:** Dusts are removed through precipitate force using the electrostatic precipitators. The gas in its raw form moves through at top velocity the channels of the precipitator made up of metallic plates. Fine particles are then collected at the collector plates, deposited through the hooper beneath the precipitator at designated intervals. Application of the electrostatic precipitators is much better way of eradicating dust from the cement process compared to the use of other process equipment as stated by Alabi [19].
- e. **Gravity settling chambers:** The raw gas goes in through the settling chamber with an area of large cross-section, at perpendicular distance to the gas outlet. Due to the perpendicular alignment, velocity drops with huge number of particulates leaving and trapped in the hoopers [19].
- f. **Cyclones:** Particulate matters enter the cyclones at high velocity through cylindrical chamber. The dusts are separated at low efficiency but can be efficiency can be increased if the cyclones are designed to obtain best results. Optimization can be better modelled in terms of hole size, diameter, thickness of the cyclones [19].

3.5. Management of wastes and emissions from cement industry to avoid pollution

There are proven methods by which wastes from cement industry can be manage to prevent degradation to the ecosystem.

- a. **Reuse:** Solid wastes can be managed according to Alabi [19], by re-using these wastes as raw materials for a new cement manufacturing process. The wastes are mixed, grinded, and dried. The mixture undergoes heating in a kiln, then forms clinker. Solid wastes when reused preserve money, energy and tackle the issue of pollution [5]. It also creates a clean environment brings the creative ability in man. Reuse of solid wastes comes from the perspective that wastes could still be useful for another cement manufacturing process, this is a foresight. Rather than rejecting these solid wastes to contaminate the environment, reuse is a safer manner. Examples of solid wastes for the cement industry to undergo reuse include newspapers, books, metal parts, fly ash, shells, bagasse, etc [26]. The solid wastes are usually burned or crushed for reuse to take place. Crushing is usually done with ball mill crusher [27].
- b. **Recycling:** Materials like plastics, scrap tyres, waste water, waste alkaline, waste acids, waste oils are recycled with the raw materials in the cement manufacturing process. This is done under strict check to meet the required standards. Recycling reduces the need of landfills and waste incinerators. Scrap tyres give that strength to cement when used mixed with other raw materials [28]. These materials serve as alternative fuels in the cement clinkering process since there is an advantage in terms of high temperature resistance, good alkaline nature and longer time retention of products in combustion. With the high alkaline nature to the atmosphere, the acidic gases from chlorides and sulphides oxidation are withheld. Recycling of plastics or scrap tyres as alternative fuels reduce emissions of CO, VOCs, NO_x or SO_x [29].
- c. **Reduce:** Domestic liquid wastes (liquid mixture of wood, paper, household wastewater, fats etc) from the cement industry are re-used in another cement manufacturing process, though this industry does not release industrial liquid waste (metals scraps, sewers, oil, gravel, chemicals etc). As a result, the liquid wastes released have been reduced [19]. Noise pollutants from machineries can be reduced by installing in machineries in soundproof boxes. Noises from air ducts can be managed by use of silencers to reduce the sound speed near the flow channels. Noises are mainly kept at a minimum of three decibels [30].
- d. **Ban:** Cement processing, waste treatment and waste disposals from the cement industry should meet regulatory guidelines from the environmental bodies e.g., NEMA (National Emergency Management Agency). For any activities that does not meet the guidelines, such activity should be banned or the organization should be fined. Quality checks are maintained [31] such as the setting time should be regulated. Settling time not regulated lead to retardation and failure of the binder to hold contaminants. Optimum moisture content for the setting is checked so undesired contaminants like leach would not be filled in the cement manufacturing process. Stabilized control in quality for cement wastes is normally 25 to 75 percent of total dry mass [31]. Other checks include hydraulic conductivity and compressive strength.
Alternative fuels such as tires, metals, plastics, impregnated saw dusts, sewage sludge etc since they emit lesser amounts of CO₂, NO_x and SO_x. Metals such as cadmium, lead, platinum, mercury, nickel or chromium [32] are seen as carcinogenic and toxic to the environment and life when they are emitted [33], hence the cement industry should be banned from using such metals as alternative fuels or recycling in form of raw materials in the manufacturing process [34].
- e. **Enlightenment:** There should be proper waste management program for the cement industry and the society as a whole. The cement industry should enlighten the public on how to dispose waste so as to recycle for the manufacturing purpose. Such organization should understand pre-treatment technique for a serene environment, pre-treatment techniques like pyrolysis, torrefaction and in-line mixing [35]. In order to reduce emissions like CO₂ or SO_x. Workers in the cement industry should undergo training, orientation on work operation in a healthy and safe environment. These techniques influence the behaviours in people on how to create a clear environment [36].

4. Conclusion and Recommendation

The cement industry produced emissions that lead to global warming, imbalance of the ecosystem, and health issues, hence proper control and management are needed to minimize the emission of pollutants to the environment. Hence, this article will be useful to the producers in the cement industry and spur interest in researchers for further research. Through review from various authors, it is recommended that:

- The device that separates dusts as pollutants with a higher efficiency should be maintained to get a rather cleaner gas released to the atmosphere. Example of such is the use of electrostatic precipitators;
- The environmental inspection body should investigate the cement industries to examine the number of pollutants emitted, the type of machineries used, ways of wastes disposals. This is done to reduce the pollutants released and maintain high quality operations in the industry; and
- More research should be carried out to investigate the separation process in the cement industry. Separation processes like the gas-solid to give the right models for designing more separation equipment.

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Contribution to SDG's

The research contributes to the SDGs in the following categories:

- The environmental pollutants associated with cement industry are highlighted for immediate control.
- The remediation and treatment techniques are identified for implementation.

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