Journal Of Research Technology & Engineering
www.jrte.org

Cement Manufacturing Process and Its Environmental Impact

*L.P.S.S. Panagoda, , R.A.H.T. Sandeepa, W.A.V.T. Perera, D.M.I. Sandunika, S.M.G.T. Siriwardhana, M.K.S.D. Alwis, S.H.S. Dilka.

Faculty of Technology, University of University of Sri Jayewardenepura
*sanujasamadith@gmail.com

Received:02 July 2023; Revised: 05 July 2023; Accepted: 07 July 2023; Available online: 10 July 2023

Abstract: Cement manufacturing is a significant industrial activity that plays a vital role in the construction sector. However, the process of cement production is associated with various environmental impacts, raising concerns about sustainability. This abstract provides a concise overview of the cement manufacturing process and its environmental implications. The cement manufacturing process involves the extraction and processing of raw materials, such as limestone, clay, and shale, which are then heated in a kiln at high temperatures to form clinker. The clinker is finely ground with gypsum and other additives to produce cement. This process consumes substantial amounts of energy, primarily in the form of fossil fuels, leading to significant carbon dioxide (CO_2) emissions. The cement industry is one of the major contributors to global greenhouse gas emissions, accounting for approximately 8% of total anthropogenic CO_2 emissions. Apart from CO_2 emissions, cement production also generates other environmental impacts. The mining of raw materials can result in habitat destruction, soil erosion, and water pollution. The high temperatures in the kiln lead to the release of pollutants, including nitrogen oxides (NOx), sulfur oxides (Sox), and particulate matter (PM), contributing to air pollution and respiratory problems. Furthermore, the transportation of raw materials and finished cement adds to the carbon footprint of the industry. To mitigate these environmental impacts, the cement industry has been adopting various strategies. Energy-efficient technologies, such as the use of alternative fuels and the development of more sustainable kiln designs, are being implemented to reduce CO_2 emissions. Moreover, efforts are underway to promote the use of supplementary cementitious materials and blended cement, reducing the clinker content and enhancing the sustainability of concrete construction.

Index Terms: Cement Manufacturing, Environmental impact, Environmental Pollution, Carbon emissions

1 Introduction

Cement is an extremely important construction material used for housing and infrastructure development and a key to economic growth [1]. Concrete is the most used of all the building materials in the world due to its unique advantages compared to other materials. The main reasons for its fame are that concrete has excellent mechanical features and is affordable. Moreover, conventional concrete is estimated to be produced about 6 billion tons every year worldwide. The vital role of cement as a sole binder in concrete that results in the formation of solid material with the ability to sustain load is undeniable. It is important to highlight that Ordinary Portland cement has been used as an important ingredient of concrete material in construction for even more than 200 years [2].

Cement is any substance that binds together other materials by a combination of chemical processes known collectively as setting. Cement is an extremely important construction material. It is used in the production of the many structures that make up the modern world including buildings, bridges, harbors, runways, and roads. It is also used for facades and other decorative features on buildings. The constant demand for all these structures, increasingly from the developing world, means that cement is the second most consumed commodity in the world after water [3].

The cement industry contributes significantly to the imbalances of the environment, in particular air quality. The key environmental emissions are nitrogen oxides (NO_x), sulfur dioxide (SO_2), and grey dust [1]. The Portland cement manufacturing industry is under scrutiny these days because of the large volumes of CO_2 emitted. However, higher production levels have also been largely labeled as the leading cause of pollution. The main sources of air pollution in the industry include excavation activities, dumps, tips, conveyer belts, crushing mills, and kiln emissions [1]. The cement production technologies in use cause extensive power consumption, gas emissions, noise pollution environmental heating, and emissions of fuel (CO_2, NO_X SO_2, and CO) from the kiln and precalciner. These are the major sources of environmental pollution in the cement industry to the best possible extent [4].

2 RAW MATERIALS FOR CEMENT PRODUCTION.

Cement is produced from raw materials such as limestone, chalk, shale, clay, and sand [1]. Table 1 indicates the raw ingredients used to provide each of the main cement elements.

Table 1. Raw ingredients are used to provide each of the main cement elements.[3]

Calcium	**Silicon**	**Aluminum**	**Iron**
Limestone	Clay	Clay	Clay
Marl	Marl	Shale	Iron ore
Calcite	Sand	Fly ash	Mill scale
Aragonite	Shale	Aluminum	Shale
Shale	Fly ash		Blast furnace dust
Seashells	Rice hull ash		
Cement kiln dust	Slag		

3 CEMENT PRODUCTION

Fig. 1 Illustrates the Cement Production Flow Sheet By the dry process below.

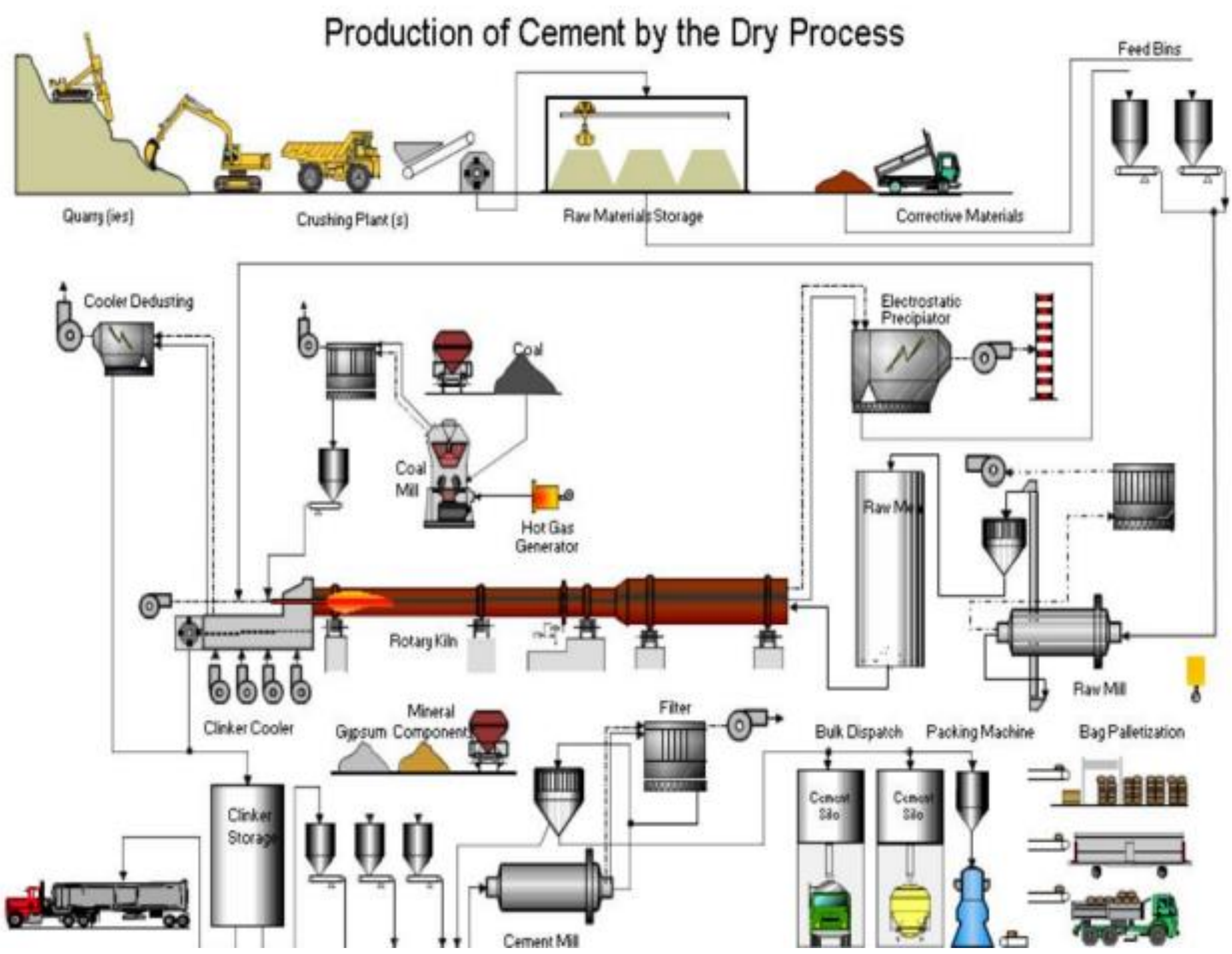

Fig. 1. The Cement Production Flow Sheet By the dry process [5]

3.1 Quarrying and Raw Material Preparation:

In the quarrying process, raw materials such as limestone, clay, or shale are extracted from quarries using blasting or drilling techniques. The extracted materials are then transported to the cement plant, where they undergo crushing, grinding, and blending to create a uniform raw mix [6]. This process ensures that the raw materials are properly proportioned and homogenized, allowing for the consistent quality and chemical composition of the raw mix.

3.2 Raw Mix Grinding:

The raw mix, consisting of crushed and blended raw materials, is further ground into a fine powder in a grinding mill. The most used mills for this purpose are ball mills or vertical roller mills [7]. These mills utilize mechanical forces to reduce the particle size of the raw mix, increasing its surface area and enhancing the chemical reactions during the subsequent processes.

3.3 Preheating and Pre-calcining:

To improve energy efficiency and reduce fuel consumption, the powdered raw mix undergoes preheating and precalcination. The raw mix enters a preheater, where it comes into contact with hot gases from the kiln. This preheating step helps to remove moisture and preheat the raw mix before it enters the kiln [8]. The preheated raw mix then moves to the pre-calciner, where partial decomposition of carbonates occurs, further reducing the energy requirement during clinker formation [7].

3.4 Clinker Production:

The preheated and precalcined raw mix is fed into a rotary kiln, a large cylindrical furnace. Inside the kiln, the raw mix is subjected to high temperatures (around 1,450°C or 2,642°F) and a long residence time. This thermal treatment causes chemical reactions, including the formation of clinker. A clinker is a nodular material with hydraulic properties that serve as the main ingredient for cement [6]. The composition and quality of clinker have a significant impact on the properties of the final cement product.

3.5 Cement Grinding:

The clinker, along with a small amount of gypsum, is finely ground in a cement mill to produce cement. The grinding process is typically carried out using ball mills, which are horizontal rotating cylinders containing steel or ceramic balls. The clinker and gypsum are fed into the mill, where they are ground to a fine powder. The addition of gypsum regulates the setting time of cement and enhances its workability [9].

3.6 Cement Storage and Packaging:

After grinding, the cement is stored in silos before being dispatched to customers. Proper storage conditions are crucial to maintaining the quality and stability of the cement. Depending on the mode of transportation and customer requirements, cement can be shipped in bulk or packed into bags for distribution [1–9].

4 ENVIRONMENTAL IMPACT.

4.1 Emissions from Cement Industry.

a. **Gases & VOCs:**

Gaseous air emissions of CO_2, NOx, SO_2, volatile organic compounds (VOCs), and other carbon Dioxide are released during the manufacturing of clinker, a cement component containing calcium carbonate ($CaCO_3$). are fired in a rotary kiln to initiate a sequence of complex chemical processes [10]. Specifically, CO_2 is emitted as a by-product during calcination, which occurs at the higher, colder end of the furnace or in a pre-calciner. The temperature is 600–900 °C, and the carbonate is transformed into oxide. Sulfur oxides and nitrogen oxides are created by the kiln and drying operations. Sulfur dioxide is created from the sulfur compounds in the ores and the combusted fuel and varies in amount from plant to plant. The combustion of fuel in rotary cement kilns generates nitrogen oxides from the nitrogen in the fuel and the entering combustion air [11]. Volatile organic carbon compounds (VOCs) are a class of chemicals that are discharged directly into the air because of evaporation or another sort of volatilization. Sources include stored gasoline, stored solvents and other industrial chemicals, and certain industrial operations. The incomplete combustion of fuels of several sorts is also a substantial source of VOC discharge to the ambient air [10].

b. **Dust:**

Dust emissions originate mainly from the raw mills, the kiln system, the clinker cooler, and the cement mills. A basic feature of these process steps is that hot exhaust gas or exhaust air is passing through crushed material, resulting in a closely dispersed mixture of gas and particles. The nature of the particles created is linked to the source material itself, that is, raw materials (partly calcined), clinker, or cement [1].

c. **Noise:**

Noise emissions occur throughout the whole cement manufacturing process, from preparing and processing raw materials to the clinker combustion and cement production processes, from material storage to the dispatch and shipment of the final products. The heavy machinery and large fans used in various parts of the cement manufacturing process can give rise to noise and/or vibration emissions, particularly from chutes and hoppers; any operations involving fracture, crushing, milling, and screening of raw materials, fuels, clinker, and cement; exhaust fans; blowers; and duct vibration [1].

d. **Wastewater:**

Stormwater flowing through pet coke, coal, and waste material stockpiles exposed to the open air may become contaminated with water streams. If stormwater does contact the storage yard, it may indicate the presence of high levels of sulfate in the soil, toxic metals like Zinc, lead, and Chromium in the dust, and a high TDS value in the groundwater [5].

e. **Bad Odor:**

A foul smell is sometimes a direct consequence of the gases emitted during cement manufacturing. Moreover, since cement Manufacturing has life-threatening impacts on plants and animals; the manufacturing process then directly and indirectly gives rise to offensive smells as the deceased plants and animals decay [1].

4.2 Environmental Pollution and Its Impact.

Dust emissions are a significant source of environmental pollution during cement manufacturing; for example, dust is generated during the transportation, loading, and unloading of the clinker to be deposited outside the silo [2]. The cement industry requires a large quantity of energy to use in the whole process and to generate this, non-renewable resources like fossil fuel are required. Even though some renewable resources are used in some industries, a large quantity of fossil fuel is still used for this process. So due to this matter, significant impacts on the environment are CO_2, CO, NO_X, SO_X, and VOCs [5]. CO_2 is indeed one of the major greenhouse gas emissions and a significant contributor to global warming. During the formation of CaO through cement production, CO2 will be released with water vapor at high temperatures. It is responsible for 5% to 7% of global CO_2 emissions from total industrial energy utilization, and CO_2 also accounts for 65% of greenhouse gases [2]. The emission of those gases into the atmosphere is not only causing environmental problems but also affecting public health. Climate change, global warming, ozone depletion, acid rain, biodiversity loss, reduced crop productivity, etc. [2].

a. Atomic dirt: these atoms permeate the lung and cause significant damage to the respiratory tract (diseases such as asthma, chronic cough, and inflammatory coral aerobics). And these emissions consist of ash, soot, and carbon components, which are often the result of incomplete combustion processes [3].

b. Sulfur Oxides: The air pollution induced by sulfur is one of the most dangerous air pollutants. The sulfur compounds cause significant problems for animals, plants, and buildings because acid rain causes corrosion of metals, limestone, and other materials. For example, but not limited to [3].
c. NOx: Nitrogen monoxide has the same negative effect on the environment as the first carbon dioxide, which can combine with hemoglobin cells to limit the ability of blood to carry oxygen, and nitrogen dioxide causes inflammation of coral bronchial pneumonia [3].
d. Carbon dioxide: It is one of the greenhouse gases that induce global warming. These gases absorb heat radiation and store it, which contributes to increasing the surface temperature [3].

The manufacturing process of cement also causes dust pollution, which may reduce the visibility and quality of the air. When the dust has been drained, it can contaminate the water and cause adverse effects on human well-being or even on animals, as plainly stated by the Centers for Disease Control and Prevention. Wastewater discharge into the atmosphere is responsible for contaminating water supplies from rivers or groundwater supplies. In areas with a growing population, building, and urbanization, as well as human activities on land, contribute to soil degradation problems [2].

Noise pollution occurs during the complete cement-producing process. From preparing raw materials to the clinker burning and production processes to material storage, the heavy machinery and big fans employed in the process led to noise pollution [5]. Noise pollution not only affects human hearing, but it also adversely affects the anatomy and physiology of human body systems such as the nervous, digestive, and cardiovascular [2].

In cement manufacturing, solid waste mainly comprises clinker production and spoil rocks, which are removed from the raw materials during the raw metal preparation. Kiln dust and fly ash from power plants are also included in solid waste. Deposits of dust in open areas cause land degradation and deposit dust over plant foliage. Another waste generated from plant maintenance is used oil and metal scrap. Fig. 2 shows the summarization diagram of the impact of cement production. Mostly, these wastes are disposed of in landfills in the open air, which causes several respiratory diseases [5]

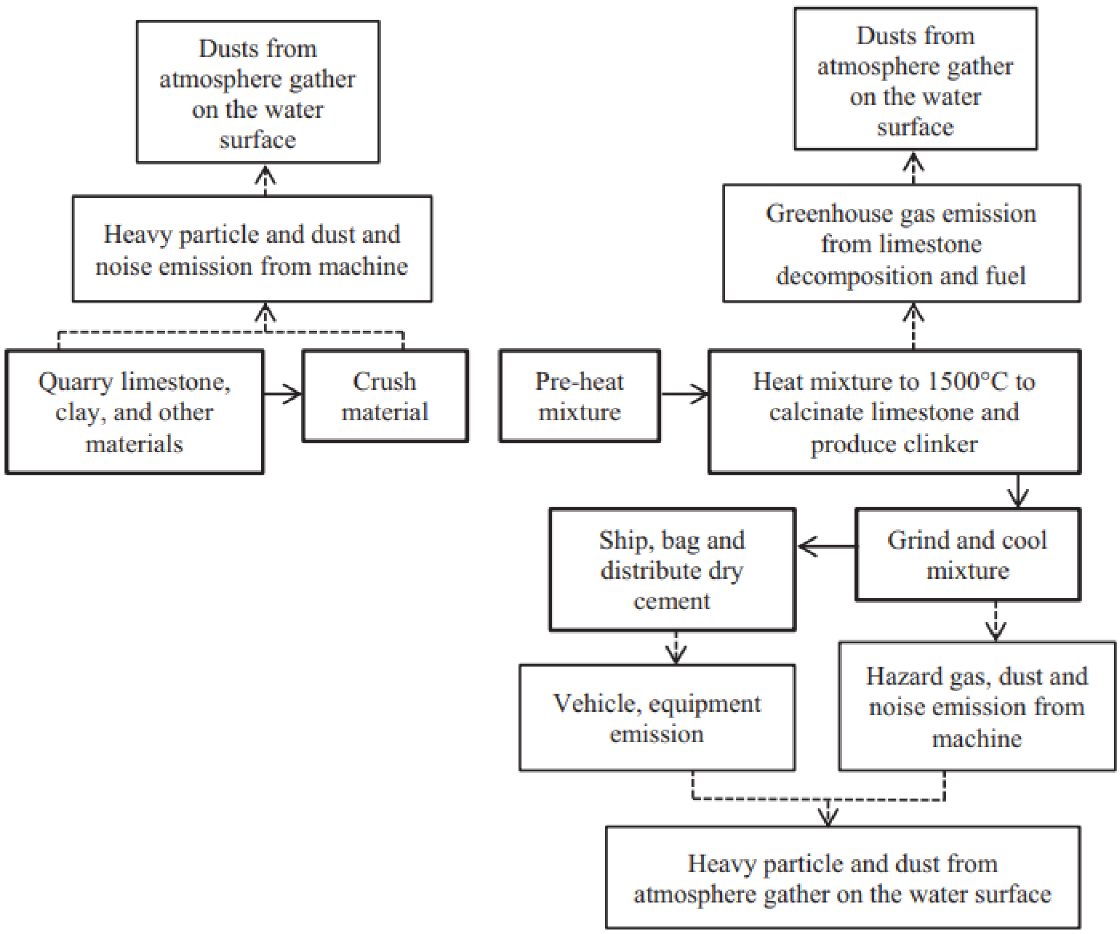

Fig. 2. Summarization diagram on the impact of cement production [2]

5 CONCLUSION

The cement manufacturing process has a substantial environmental impact, primarily due to its high energy consumption, significant carbon dioxide (CO2) emissions, and the release of various pollutants. The extraction and processing of raw materials, along with the burning of fossil fuels in the kiln, contribute to habitat destruction, soil erosion, water pollution, air pollution, and respiratory problems. However, the cement industry has recognized these challenges and has been actively working towards mitigating its environmental footprint. Efforts are being made to adopt energy-efficient technologies, such as the use of alternative fuels and the development of sustainable kiln designs, to reduce CO2 emissions. Additionally, the promotion of supplementary cementitious materials and blended cement helps reduce the clinker content and enhance the sustainability of concrete construction. To further address these environmental concerns, collaboration among stakeholders is crucial. Governments can implement stricter regulations and standards to limit emissions and promote sustainable practices in the cement industry. Manufacturers and researchers can continue to invest in research and development to identify innovative solutions, such as carbon capture and utilization, to reduce the CO2 emissions associated with cement production. Furthermore, sustainable construction practices, such as the use of eco-friendly building materials, efficient transportation systems, and waste management strategies, can contribute to minimizing the environmental impact of cement production throughout the entire lifecycle of construction projects. Overall, while the cement manufacturing process currently poses significant environmental challenges, the industry's commitment to sustainable practices, technological advancements, and collaboration among stakeholders offer hope for a greener future. By continuing to prioritize sustainability, the cement sector can reduce its environmental impact and contribute to a more sustainable and resilient construction industry.

REFERENCES

[1] Devi, K.S., Lakshmi, V.V. and Alakanandana, A., 2017. Impacts of cement industry on environment-an overview. Asia Pac. J. Res, 1, pp.156-161.

[2] Mohamad, Nabilla & Muthusamy, Khairunisa & Embong, Rahimah & Kusbiantoro, Andri & Hashim, Mohd. (2021). Environmental impact of cement production and Solutions: A review. Materials Today: Proceedings. 48. 10.1016/j.matpr.2021.02.212.

[3] Mohsen, M.M. (2015) Cement Manufacturing , Researchgate. Available at: https://www.researchgate.net/publication/286381802_Cement_Manufacturing (Accessed: 10 July 2023).

[4] Nisa, Z. (2008)   Cement and its effect to the environment: A case study in SriLanka, Fachwissen seit über 80 Jahren - Fraunhofer IRB. Available at: https://www.irb.fraunhofer.de/CIBlibrary/search-quick-result-list.jsp?A&idSuche=CIB%2BDC11336 (Accessed: 10 July 2023).

[5] Arachchige, U.S.P.R. et al. (2019) Environmental Pollution by Cement Industry, International Journal of Research. Available at: https://journals.pen2print.org/index.php/ijr/ (Accessed: 10 July 2023).

[6] Manufacturing process (no date) Lafarge. Available at: https://www.lafarge.com.eg/en/2_2_1-Manufacturing_process (Accessed: 03 July 2023).

[7] Chatterjee, A.K., 2018. *Cement production technology: Principles and practice*. CRC Press.

[8] Hasan, S.T. (no date b) Syeda Tahsin Hasan, Civil Engineering. Available at: https://civiltoday.com/civil-engineering-materials/cement/106-cement-manufacturing-process (Accessed: 04 July 2023).

[9] How cement is made (no date) How Cement Is Made. Available at: https://www.cement.org/cement-concrete/how-cement-is-made (Accessed: 04 July 2023).

[10] Gibbs , M.J., Soyka, P. and Conneely , D. (no date) CO2 emmisions from cement production, Intergovernmental Panel on Climate Change. Available at: https://www.ipcc-nggip.iges.or.jp/public/gp/bgp/3_1_Cement_Production.pdf (Accessed: 10 July 2023).

[11] Zimwara1, L. Mugwagwa1, and T.R Chikowore.2012. Air Pollution Control Techniques For the Cement Manufacturing Industry: A Case Study for Zimbabwe. Department of Industrial and Manufacturing Engineering. National University of Science and Technology, Zimbabwe, CIE42 Proceedings, 16-18 July 2012, Cape Town, South Africa. CIE & SAIIE. P.No .37-1 -37-13.