A Review On Environmental and Health Impacts Of Cement Manufacturing Emissions

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Abstract: ***Climate change is considered as major environmental challenge for the world. Emissions from cement manufacturing are one of the major contributors in global warming and climate change. Cement manufacturing is a highly energy intensive process, which involves intensive fuel consumption for clinker making and resulting in emissions. Beside Fuel consumption, the calcining process is a major source of emissions such as NOx, SOx, CO2, particulate matters etc. In this paper, the role of cement industry is reviewed in causing impact on environment and health. It describes the cement production process and its emission sources followed by overview of emissions and their environmental and health impacts. Review study has focused on emission generation from clinker production and excluded the emissions due to indirect energy (electricity, transportation, supply chain etc.) used for cement operations. This review observed a comprehensive literature in term of peer reviewed journals, industry sector reports, websites etc on cement industry and associated emissions and health impacts.***

Keywords: Cement manufacturing, emissions, SO_2, NO_x, PMs, CO_2, environmental impact, health impacts, sustainability.

1. Introduction

It is impossible to envisage a modern life without cement. Cement is an extremely important construction material used for housing and infrastructure development and a key to economic growth**.** Cement demand is directly associated to economic growth and many growing economies are striving for rapid infrastructure development which underlines the tremendous growth in cement production **[1].** The cement industry plays a major role in improving living standard all over the world by creating direct employment and providing multiple cascading economic benefits to associated industries. Despite its popularity and profitability, the cement industry faces many challenges due to environmental concerns and sustainability issues **[2]**.

The cement industry is an energy intensive and significant contributor to climate change. The major environment health and safety issues associated with cement production are emissions to air and energy use. Cement manufacturing requires huge amount of non renewable resources like raw material and fossil fuels. It is estimated that 5-6% of all carbon dioxide greenhouse gases generated by human activities originates from cement production **[2]**. Raw material and Energy consumption result in emissions to air which include dust and gases. The exhaust gases from a cement kiln contains are nitrogen oxides (NOx), carbon dioxide, water, oxygen and small quantities of dust, chlorides, fluorides, sulfur dioxide, carbon monoxide , and still smaller quantities of organic compounds and heavy metals **[3]**. Toxic metals and organic compounds are released when industrial waste is burnt in cement kiln. Other sources of dust emissions include the clinker cooler, crushers, grinders, and materials-handling equipment.

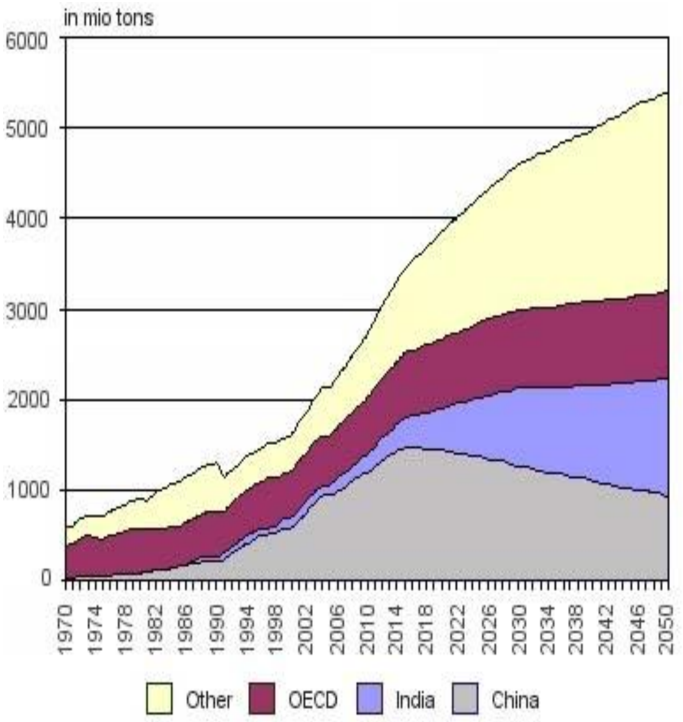

Figure 1: Global Cement Production 1970-2050 **(**Source: International Energy Agency (IEA)

These emissions are not only deteriorating air quality but also degrading human health. Emissions have local and global environment impact resulting in global warming, ozone depletion, acid rain, biodiversity loss, reduced crop productivity etc **[4]**. Scientific evidence indicates that air pollution from the combustion of fossil fuels causes a spectrum of health effects from allergy to death **[5].** The results of several studies showed that these emissions are adversely affecting human health in a variety of ways, like itchy eyes, respiratory diseases like tuberculosis, chest discomfort, chronic bronchitis, asthma attacks, cardio-vascular diseases and even premature death **[6], [7]**.

2. Cement Manufacturing Process:

The main component of cement is clinker, which is produced from raw materials, such as limestone and clay. **[8]**. Limestone supplies $CaCO_3$ for the cement production. Silica, alumina, and iron are considered to be other raw materials. The lime stone used for cement manufacturing contains 75-90 % of $CaCo_3$ and remainder is $MgCo_3$ and impurities **[11]**. Raw material is extracted through mining and quarrying which follows drilling, blasting, excavating, handling, loading, hauling, crushing, screening, stockpiling, and storing **[10]**.

A specific composition of the raw materials are crushed and then milled into a raw meal for the quality and uniformity of cement. This raw meal is blended in blending silos and is then heated in the pre-heating system. This process dissociates carbonate to calcium oxide and carbon dioxide **[11]**. It can be accomplished by any of three processes: the dry process, the wet process, or the semidry process **[10]**. In a dry cement manufacturing process, dry raw mix contains less than 20% moisture by mass. However, in a wet process water is added to the raw mix to form slurry and then is transported to the kiln **[11]**.

Raw meal or blended raw materials are fed into the upper end of the pre-heater tower and then passed through the end of the rotary Kiln. A rotary kiln is a tube with a diameter up to about 6 m. which is installed at a horizontal angle of 3^o–4^o and rotates slowly with about one to four RPM **[9]**. The Kiln rotates and the ground raw material moves down toward the flame. As the temperature increases, the sequence of chemical and physical changes starts with reaction taking place between calcium oxide and other elements. This reaction will produce calcium silicates and aluminates at about 1500° C. The flame can be produced by fuel materials such as coal, petroleum coke, or by natural gas, oil, biomass, industrial waste and recycled materials. A series of chemical reactions will take place and the raw material will be melted and fused together to form a clinker. The clinker is discharged as red-hot at approximately 1500^oC from the end of the kiln, which is passed through coolers, where the excess heat is recovered. Most commonly cooling of the clinker can be performed in a grate cooler, a tube (rotary) cooler, or a planetary cooler. It recovers up to 30% of kiln system heat and route it back to the pre-heater units **[9], [10], [11], [12]**.

In the final step, clinker is ground together with additives (e.g., fly ash, blast furnace slag, pozzolana, gypsum, and anhydrite) in a cement mill to control the properties of the cement. Combinations of milling techniques including ball mills, roller mills, or roller presses are often applied to ground clinker with additives in cement mill. The finished cement is being transferred via bucket elevators and conveyors to silo for storage **[9]**.

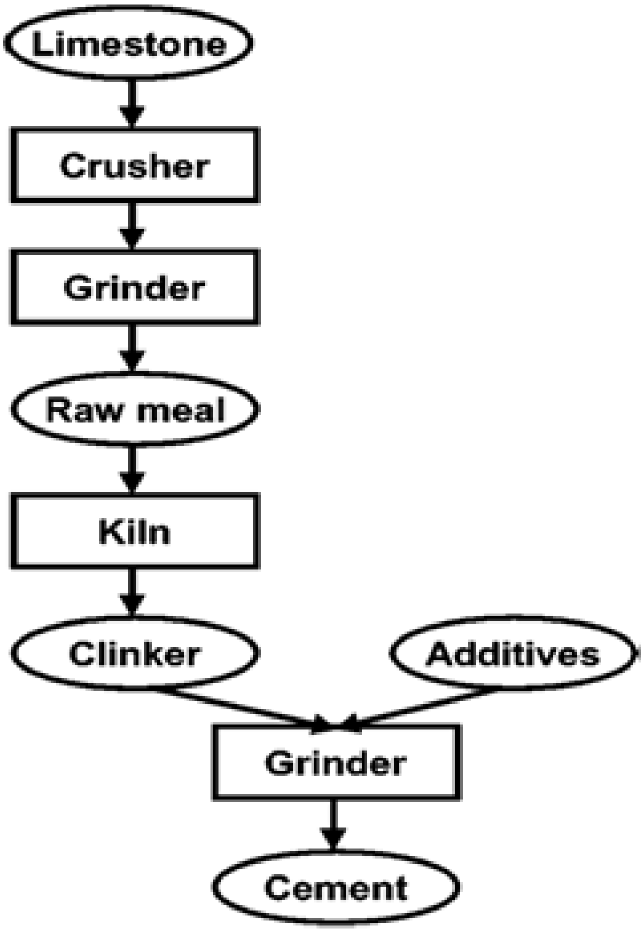

Figure 2: Cement Manufacturing Process

3. Emissions from cement manufacturing

The most significant environment health and safety issue of cement manufacturing is emission **[15]**. Cement industry is potential anthropogenic source of air pollution. It has estimated that cement production originates about 5% of global manmade CO_2 emissions **[13]**. The typical gaseous emissions to air from cement production include NOx, SOx, CO, CO_2, H_2S, VOCs, dioxins, furans and particulate matters **[14], [15], [16]**. These major pollutants can be classified in two categories- gaseous and particulates. Fuel combustion process is the source of gaseous emissions which include oxides of nitrogen, oxides of sulfur, oxides of carbon and volatile organic compounds and hydrogen sulfide. Quarrying, drilling, blasting, hauling, Cement mill, fuel preparation, packaging, road cleaning and stacks are sources of particulate matter in the form of dust and carbon particle **[14], [15], [16]**.

There are many other sources of emissions from cement manufacturing, such as emissions from transportation equipment used in the mining and transporting raw and finished material, fuel used for electricity production for operating other process in cement manufacturing **[23]**.
Types of fuel used in cement industries for few selected countries **[11]**

Process	[19], [20]	
Raw mill	SO_2 Formation	Sulfides + $O_2 \rightarrow$ Oxides + SO_2 Organic S + $O_2 \rightarrow SO_2$
	SO_2 Absorption	$CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$
Preheating zone	SO_2 Formation	Sulfides + $O_2 \rightarrow$ Oxides + SO_2 Organic S + $O_2 \rightarrow SO_2$
	SO_2 Absorption	$CaCO_3 + SO_2 \rightarrow CaSO_3 + CO_2$
Calcining zone	SO_2 Formation	Fuel S + $O_2 \rightarrow SO_2$ $CaSO_4 + C \rightarrow CaO + SO_2 + CO$
	SO_2 Absorption	$CaO + SO_2 \rightarrow CaSO_3$ $CaSO_3 + ½ O_2 \rightarrow CaSO_4$
Burning zone	SO_2 Formation	Fuel S + $O_2 \rightarrow SO_2$ Sulfates $\rightarrow$ Oxides + SO_2 + ½ O_2
	SO_2 Absorption	$NaO + SO_2 + ½ O_2 \rightarrow NaSO_4$ $K_2O + SO_2 + ½ O_2 \rightarrow K_2SO_4$ $CaO + SO_2 + ½ O_2 \rightarrow CaSO_4$

Table 1: Types of fuel used in cement industries

Types of fuel	Energy % Share	Country
Electricity	11–14	Canada and India
Coal	33–41	Canada and India
Natural gas	7–64	Canada, Iran and India
Biomass	19	India
Petro-coke	13	Canada

4. Environmental and Health Impact of emissions

Air pollution from Cement manufacturing is becoming an environmental problem worldwide. Recent studies determine relationship between cement air pollution and human health diseases. Pollutants from cement plants are causing harmful effects on human health and environment **[13]**.

Sulphur Oxide (SOx):

Oxides of sulphur are formed from the combustion of fuels which contain sulphur and oxidation of sulphur containing raw material **[18]**. Sulfur is present in all cement raw materials. SO_2 Emissions generated from sulphur in the raw materials are lesser than SO_2 emissions generated from sulfur in the fuel **[16]**. In rotary kiln raw material oxidized to form SO_2 and SO_3 at temperature between 370^o C and 420^o C prevailing in the kiln preheater **[15]**. Sulfur dioxide (SO_2) is formed by thermal decomposition of calcium sulfate in clinker. SO_3 is present as anhydrite and can easily be decomposed to SO_2 and O_2. But the highly alkaline condition in the kiln can absorb 90% of the sulphur oxides. Sox emission can be controlled by using low slphur fuel and raw material.

Table 2: Process SO_2 Emission

The sulfur oxides react with water vapor and other chemicals high in the atmosphere in the presence of sunlight to form sulfuric acids. The acids formed usually dissolve in the suspended water droplets, which can be washed from the air on to the soil by rain or snow. This is known as acid rain. It is responsible for so much damage to life and health. Respiratory illnesses such as bronchitis are seen to increase with sulfur oxide levels **[21]**. Increased level of SOx in the atmosphere can also degrade agricultural productivity and death of some plants.

Nitrogen Oxide (NOx):

Nitrogen oxides are produced in the combustion flame of a rotary kiln, which enter the atmosphere with the exit gases, and undergo many reactions in the atmosphere. Majorly NOx are formed by thermal oxidation, which happens in temperature range between 1,200-1,600 °C. Due to high temperature significant amounts of thermal NO are generated in the Kiln. Combustion of nitrogen-bearing fuels such as certain coals also produces N_2, or NO. **[16]**.

$$N_2 + O \rightarrow NO + N$$
$$N + O_2 \rightarrow NO + O$$

As temperature increases, NO formation also increases. About 90% of the nitrogen oxides are produced in the form of nitric oxide (NO) and the remaining 10% are in the form of nitrogen dioxide (NO_2) **[21]**.

Produced NO converts to NO_2 at the exit of the stack at atmospheric conditions and appears in brown-yellow color.

$$NO + 1/2O_2 \rightarrow NO_2$$ **[16]**.

NOx causes a wide variety of health and environmental impacts because of various compounds and derivatives in the family of nitrogen oxides, including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide.

Similar to sulphur dioxide, NOx react with water and other compounds to form various acidic compounds. When these acidic compounds that are deposited to the earth's surface, they can impair the water quality of different water bodies and acidify lakes and streams. Acidification (low pH) and the chemical changes result in making it difficult for some fish and other aquatic species to survive, grow, and reproduce. Acid rain can also harm forest ecosystems by directly damaging plant tissues **[22].**

Nitrous oxide is a greenhouse gas and it accumulates in the atmosphere with other greenhouse gasses causing a gradual rise in the earth's temperature. This will lead to global warming and climate change.

NOx and volatile organic compounds react in the atmosphere in the presence of sunlight to form ground-level ozone, which causes smog in cities and rural areas. This ground level ozone when breathed, it causes respiratory disease and other health problems **[22]**. Nitrogen dioxide affects body functions such as difficulty in breathing, chronic lung diseases, such as chronic inflammation and irreversible structural changes in the lungs, which with repeated exposure, can lead to premature aging of the lungs and other respiratory illness. Studies indicate positive relation between nitrogen dioxide concentrations and heart disease and cancer cases **[21]**.

Carbon dioxide (CO_2) & CO:

Cement industry is a major source of CO_2 emission. CO_2 is emitted from the calcinations process of limestone and from combustion of fuels in kiln. It estimates that half of the CO_2 is generated from fuel combustion and half originates from decarbonization of raw material. An indirect source of CO_2 and other pollutant in cement production is from consumption of electricity, assuming that the electricity is generated from fossil fuels. **[9]**.

$CaCO_3 \rightarrow Cao + CO_2$

(1 kg 0.56 kg + 0.44 kg) [9]

$MgCO_3 \rightarrow MgO + CO_2$ [16]

The amount of CO_2 released in calcination can be calculated from the component formula weight ratios for of limestone **[24]**. CO_2 emissions from different fuels combustion can be calculated from emission factors of fuels defined by the Inter government Panel on Climate Change (IPCC) **[9]**. The amount of CO_2 emission during this process is directly related to the type of fuel used like coal, fuel oil, pet coke, natural gas, alternate fuel. Typically, kiln is fueled with coal as other fossil fuels are too expensive to be used in cement production. However carbon based waste material such as tires are commonly used in cement kiln to use its energy content **[23]**.

Table 3: CO_2 Emission Intensity (lb CO2/MMBtu) for Fuels Combusted at Cement Kilns [23]

CO_2 Emission Intensity (lb/MMBtu)					
Natural Gas	**Heavy Fuel Oil**	**Western Sub-bituminous Coal[1]**	**Tires**	**Eastern Bituminous Coal[2]**	**Petroleum Coke**
105.02	169.32	186.83	187.44	199.52	212.56
1 Origin - Rosemont Powder River Basin 2 Origin - Logan, West Virginia Source: Staudt, 2008a					

Process-related CO_2 emissions from cement production are the second largest source of industrial CO_2 emissions in the United States **[23]**. A number of studies have suggested that, the cement industry contributes about 5% of total anthropogenic CO_2 emissions, worldwide **[25]**. It has long been known that carbon dioxide emissions contribute to climate change. Constantly increasing CO_2 emissions are responsible for an increase in temperatures, which is expected to continue over the coming decades reaching up to +1.4° to +5.8°C globally by the year 2100. Increasing temperature can cause severe droughts in some parts of the world, extreme weather conditions, the loss of ecosystems and potentially hazardous health effects for people **[27]**.

Recent study details the impact of increase of temperature by carbon dioxide, the resulting air pollution would lead annually to about a thousand additional deaths and many more cases of respiratory illness and asthma in the United States. It also shows that fossil fuel CO2 increases surface ozone, carcinogens and particulate matters resulting in increase cases of asthma, death, hospitalization and cancer cases **[26]**. CO can cause harmful health effects by reducing oxygen delivery to the body's organs and tissues, as well as adverse effects on the cardiovascular and central nervous systems. CO can also contributes to the formation of smog (ground-level ozone), which can cause respiratory problems.

Emissions of CO2 from the cement manufacturing sector can be reduced by improving the energy efficiency of the process, adopting more efficient process, switching to low carbon fuel from high carbon fuels, using alternate fuels such as biomass, reducing clinker to cement ratio, removing CO2 from the flue gases **[23]**.

5. Particulate matters (PM_{10}, $PM_{2.5}$)

Particulate matters are emitted from quarrying, hauling, crushing, grinding of raw material and clinker, fuel preparation, clinker grinding and cement packing. Particulate matter is consisting of fine particles that can remain suspended in the air which include dust, soot, and liquid droplets **[16]**.

Table 4: Types of dust and their generation causes at cement plants (VDI, 1985; USEPA, 1995a) **[31]**

Type	Generation mechanism
Raw material dust	Quarrying, crushing and handling of raw material
Feed material	dust Feeding, milling, stacking, blending, reclaiming, conveying, and transferring of feed material
Cement kiln dust	Feeding and processing of materials involving countercurrent circulation of hot gases
Clinker dust	Cooling involving air circulation and open-storage of clinker
Cement dust	Feeding, milling, conveying, bagging and loading of cement materials

The main environmental problem resulting from dust emission is reduced visibility and deteriorated ambient air quality. When the dust is washed with rain, it can also pollute water bodies **[17]**. Particulate emissions contain potentially harmful toxic metals and compound such as lead, chromium, nickel, barium, which can pose serious health impact on human health. These emissions are toxic as it carries carcinogens, mutagens, immunotoxins, respiratory toxins, neurological toxins etc. Physical properties of such particles decide the degree of their effect on human health. Coarse particulate ($>PM_{10}$) are considered to cause local nuisance than creating health hazard and fine particles ($<PM_{10}$- $PM_{2.5}$) are majorly big concern for health hazard due to their repairable nature.

The main route of entry of dust particles in the body is the respiratory tract or the gastrointestinal tract or both by inhalation or swallowing **[29]**. When PM (diameter less than 10μm) are inhaled, they penetrate deep into the respiratory system and Pm less than 2.5 μm go on to the lungs and pass into the blood stream. It is determined that short term exposure to Particulate matters ($PM_{2.5}$) significantly increases the risk for cardiovascular and respiratory diseases. PM can also cause eye and throat irritation, bronchitis, lung damage, increased mortality rates, increased heart ailments **[5], [16], [21], [24], [25].** Some studies show that cement dust can cause respiratory and non respiratory diseases **[20]**.

Cement dust also affects plant productivity due to reduced chlorophyll content of the leaves which obstruct the photosynthesis process. It has adverse impact on agriculture in nearby areas.

VOCs, dioxins, heavy metals and other pollutants:

Other cement related emissions in trace quantity include VOCs, dioxins, furans, methane, heavy metals etc. The main source of VOC emission from cement kiln is organic matter present in raw material. Occurrence of VOCs is also associated with incomplete combustion. Heavy metal emission depends on content of these trace elements in fuel and raw material, which is naturally present in low concentration. In cement manufacturing dioxins are also formed in the combustion system when chlorine and organic compounds are present. Choice of raw material and fuel with low organic matter, with low content of volatile and semi-volatile heavy metals can reduce these emissions.

VOCs are precursor to ozone formation, which can also contaminate soil and ground water. It has been identified that VOCs can cause retardation of plant growth, chlorosis and necrosis in broad leaves plants. VOCs can cause potential health hazard like irritations in respiratory tract and eyes, headache, nausea, damage to liver, kidney and central nervous system. It is also known as potential carcinogen. Heavy metals and dioxins can also contaminate soil and water. Heavy metals can adversely affect plant functions and cell structure. Bioaccumulation of heavy metal can cause poising in aquatic and terrestrial life through biomagnifications. Heavy metals can cause damage to brain and nervous system, increased blood pressure, affect on gastrointestinal functions and reproduction. Dioxins and furans can also cause health impact like Skin rashes, liver damage, weight loss, reduction in immunity **[31]**.

6. Summary & Conclusion

It is well known fact that air pollution is hazardous to environment and human health. Due to infrastructure developmental activities cement industry is flourishing and resulting in the environmental deterioration and in turn degradation of the human health worldwide. The gaseous and particulate emissions from cement plants are degrading air quality and thus creating considerable environmental pollution especially air pollution **[32]**.

Recent studies and researches have listed the cement industry as one of the major contributor in global warming and climate change. Literature reviewed in this study shows the clear picture of dire consequences of emissions from cement manufacturing for rapid infrastructure growth and economic development. From this review it can be concluded that cement industry causes a tremendous harm to ecology and human health. The main environment and health concerns have identified are significant amount of fine dust and gaseous emissions. Gaseous emissions can have major impact on surroundings and ecology resulting in deteriorated environment. Workers and communities exposure to dust emission is associated with numerous health issues. For the sustainable development it is recommended to focus on effective emission control technology, energy efficiency, adoption of state of art technology and global synergy in environment friendly technologies.

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Dr. Nihal Anwar Siddiqui did his post graduation in Environmental Science and Doctorate in Environmental Biology. In addition he is also having Diploma in Industrial safety & Post Graduate Diploma in Environmental Impact Assessment. The topic of his research was on Environmental Impact Assessment. Dr Siddiqui specializes in the area of Environmental Pollution, Env.Monitoring and control techniques. Dr. Siddiqui started his carrier as Assistant Professor in Institute of Environment & Management and because of his desire to work in the real field he joined as Environmental Engineer, Paryacon Engineers a leading consultancy in the field of Env. Pollution and control.He was part of number of EIA projects, Environmental Audit and Env. Monitoring. Dr. Siddiqui got chance to work with Environmental Engineering Division of Central Pulp & Paper Research Institute as Scientist. During his stay with Environmental Eng. Div., Dr. Siddiqui work on 8 major R & D projects for various agencies like Central Pollution Control Board, New Delhi, MOEF, PWC and various projects sponsored by RAC. Dr. Siddiqui did some of the pioneer work in the area of odor Monitoring and providing control technology along with Finland Scientist. Dr. Siddiqui was also associated with Health, Safety & Environment dept of ICEM college, Muscat , Oman which is affiliated to University of Central Lancashire, UK. He has more than 90Research papers to his credit has participated in several National and Int. conferences. Dr. Siddiqui has authored 2 books vizNatural Resources & Environmental Management & Handbook on Fire & safety . Dr. Siddiqui has guided more than 50 M.Techand9 PhD thesis.