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A Review: Production of Particulate Matter As Pollutant During Cement Manufacturing In India, Its Impact on Health And Environment

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Abstract: Having over 7% of the global installed capacity India has secured the second position among the cement producers worldwide. The increase of the cement industry and greater consumption of cement is significant of the development, growth and progress of the nation in terms of increase in GDP (Gross Domestic Product). The manufacturing of various types of cement involves several steps like quarrying, drilling, blasting, hauling, milling, preparation of fuel, calcination, clinkerization, production, packaging and transportation. Surprisingly, at every step a certain amount of particulate matter is released into the environment along with the other gaseous pollutants. Toxic elements like Ar, Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn, Si and ions like nitrate, sulphate, and calcium ion are found in these emissions. The nature of the particulate matter however depends on the raw materials used. The particle size distribution and elemental composition of the particulate matter determines the extent of the impact on humans, animals, plants and the environment as a whole. Studies have shown drastic deterioration in the health of the workers and other people near the cement plants in the form of pathogenesis of lung diseases. Nevertheless, the production and use of cement cannot be stopped. However, these dangers need to be pointed out and studied further to find ways of reducing them. The review article deals with the process of cement manufacturing, release of harmful particulates into the environment, health implications as consequence and pollution, followed by resolutions.

1. INTRODUCTION

Cement is considered as one of the fundamental building materials to develop infrastructure, mainly used to make concrete or mortar and as binding agent. Cement production and consumption is an integral part of any nation's economy, also due to abundance of its raw materials geographically, cement is produced nearly in all countries. [1]. In urban world, the standard of living is greatly upgraded by the contribution from the cement industry, offering 1 ton of concrete per human being per year [2]. Holding second position as cement producer in world, Indian cement industry is considered as the oldest sector in India recruiting almost 1 million people of the country [3,4]. India witnessed a stable growth during the commencement of the planning period with an increase of 3.28 million tonnes in cement production capacity [5].

In last two decades, a robust demand in the development of cement industry is seen, as the consumption of cement has peaked a certain level in various infrastructural industries [5]. According to Kumar et. al., a hike upto a level of 67% in the housing industry, 13% in the infrastructure. 9% in the industrial construction and 11% for commercial buildings, proving to be a boon for the people [5, Indian Brand Equity Foundation (IBEF)] With an annual increase of about 5%, the construction industry accounts for about 8% towards the nation's Gross Domestic Product (GDP) as per the year 2021-22 [5]. It is not far when India would be the top most cement producer in the world with its large scale ongoing and proposed government construction strategies like "Housing for all, Pradhan Mantri Awas Yojana, (PMAY)", smart city initiative programs, housing projects, ports, roads, flyover, metro projects, etc. [5]. All these projects are catalyzing the demand for the cement sector in India. Undoubtedly, Cement industry significantly supports Indian economy and infrastructure [6]. The major contributors of particulate matter in India are construction activities, road dust, waste burning, vehicles, diesel Generator sets (DGS), industries and domestics [7]. One of the greatest and potential anthropogenic source of air pollution is the cement industry [8].

An important factor for large scale cement manufacturing in India is the availability of raw materials like limestone, clay, sand, coal etc. [8,12]. Large quarries of limestone deposits rich in calcium, silica, alumina, iron and low content of magnesium oxide (MgO) is best suited for cement industry [4]. Obtainability and chemical composition of theses raw materials determines the type of cement.

The Central Pollution Control Board (CPCB) has categorized industries by different colour codes according to the Pollution Index (PI) value. The industry wise PI is calculated as a function of its utilization of natural resources, discharge of emissions, effluents and hazardous waste materials into the environment. PI score of 60 and above falls under the red category, 41 – 59 under orange category, 21-40 under green category and upto 20 is under white category [13]. Thus, the CPCB categorizes the cement industry under the red category and one of the 17 most pollution causing industry in the world. [4,6]

Being such a major sector, cement industry is quite beneficial for Indian economy however comes along with many challenges in terms of potential pollutants [2, 14, 15]. Various studies show that cement production emits a lot of air pollution such as carbon dioxide, Sulphur dioxide, nitrogen oxides, hot water, chlorides, fluorides, heavy metals, traces of organic compounds and particulate matter in two ways –

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exhaust during the process and waste left after the process [2, 6-11, 14 -21]. All these contaminants have significant impact on the environment and that can be linked to an array of health concerns [7,14, 15, 21]. Discharge of untreated hazardous wastes from the production plants cause a threat to the soil quality, vegetation and nearby water resources by direct discharge of waste into it or surface run off. Presence of metals in it can be really harmful to the lifeforms inhabiting the land and water. In addition, all the heavy machineries used in the production process create noise pollution like gas dynamic noise, mechanical noise and electromagnetic noise [15]. Outcomes can also be seen in the form of foul smells released during the on-goings. Each of these have severe physiological and anatomical effects on the people living nearby and the workers [14, 15].

However, the massive outcome of the cement industry is measured in terms of the air pollution it causes. Carbon dioxide being the most potent air pollutant is released during calcination and clinkerization, predominantly surge the greenhouse effects several folds [22, 15]. Due to combustion activities involved during kiln and drying, oxides of Sulphur and nitrogen are also introduced to the environment [15]. Incomplete combustion of fuel, stored chemicals and gasoline release another class of chemicals called Volatile Organic Compounds (VOC) which react with atmospheric gases to form ground level ozone having perilous impacts in the form of smog. [15].

The particulate matters are one of the greatest pollutants released from the cement industry which is generated in one or the other form in every step of cement production. The harm of it can be traced to the life taking impacts seen in the workers and the areas nearby as discussed later. The particulates of different sizes ranging from 0.05 to 5.00 μm in diameter emitted from the cement industry have severe health implications which can be traced to the poor health conditions of the people exposed to it directly or indirectly. [2, 14,16, 17-20,23].

According to the World Air Quality Report 2020, 22 Indian cities were found among the 30 most polluted cities in the world [7]. The safe limit recommended by World Health Organization (WHO) for air pollution has been crossed by Indian cities by about 500% [7]. This data draws our attention towards India, the 5th most polluted country of the world according to the $PM_{2.5}$ pollution following the WHO report 2019 [7].

This review article intends to highlight the impact on health and environment of particulate matter as pollutant produced during cement production in India.

2. DISCUSSION

2.1 PROCESS OF CEMENT PRODUCTION:

Among limestone, marble, marl, shell, alkali waste, blast furnace slag, limestone is the most important and commonly used raw material because of high calcium carbonate content [1, 7]. A limestone rich land is obtained through a geological search, close to which the cement plant is built. Quarrying and excavating of the mines is done by various blasting techniques [24]. Subsequently, the extracts are crushed to gravel sizes 1.5m, 150mm and 100mm further ground to a size of 90 micron or less and sent for homogenization in the blending silos [24]. The output formed henceforth is a homogenous mixture called the raw meal prepared by mixing clay, sand and other chemicals as per the cement requirement [7,22, 24, 25].

The crude substances used for cement production, are worked upon by mechanical processes like mining, quarrying, crushing and grinding to generate raw meal of standard consistency. Then, fed into the rotary kiln where increase in temperature is achieved due to its systematical rotatory motion. This leads to calcination followed by clinkerization of the raw meal. Cooling down of the clinker takes place to remove the excess heat succeeded by mixing additives like, gypsum, to customize the property of cement. The final cement thus becomes ready to be milled, stored, bagged and transport [6,8, 9, 26].

Depending on the moisture content, there are three processes of cement manufacturing before the raw material can be fed into the kiln; the dry process, semi dry/ semi wet process and the wet process.

Dry-process - The raw material is dried using drum dryers, impact dryers, autogenous mills etc. during or before the grinding. [6]

Semi-dry/ semi-wet process- pellets of cement are made by adding water to the raw material using special devices [6].

Wet process- a slurry consistency is prepared by adding water to the raw material. Increased consumption of fuel takes place to remove the extra water making this technique unsuitable for use [6,22, 23].

In wet kilns, without dust control technology, the diameter of 24% and 7% of the emitted particles was found to be lesser than 10 and 2.5 μm, respectively and in case of the dry process plants, the diameter of 42% and 18% of the emitted particles was found to be lesser than 10 and 2.5 μm, respectively. [23, 26]. However, in both the cases, dust control technology, 85% of the total escaping particles were less than 10 μm in diameter and for the dry process using bag houses, 45% of the escaping particles had a diameter of less than 2.5μm [23]. Conclusively, the particulate matter is released during all the three processes of cement production. Exposure to the particulate matter destroys the lungs by penetrating it and can also interfere with the regular process by entering the blood vessels. It can also enhance risks of cardiovascular and respiratory diseases [27]. The review covers all the health implications of particulate matter in next segment.

Additionally, during the process, an exhaust air is passed through the pulverized materials which lead to the formation of an intimately scattered composition of gases like carbon dioxide, Sulphur dioxide, oxides of nitrogen, Volatile

Organic compounds (VOCs) and potentially harmful particulates matters (PM) [2, 6,7,15,21, 23, 28]. The quantity of emission however depends upon the type of raw material and process used. All these generated adulterants enter into the environment and affect the life of living entities [21]. Thus, cement production is one of the pollutant industries.

2.2 PARTICULATE MATTER (PM) EMISSION:

Particulate matter can be defined as a fusion of particles which can be solid in nature and aerosol (liquid droplets). Some examples of PM are dust, soot, carbon particles, fly ash, bottom ash, slag, black filter dust, smoke, fume, flue gases, dolochar, scraps, etc. [8, 29]. Based on the aerodynamic diameter, PM can be classified into three types; coarse particle, fine particle and ultrafine particle. PM of aerodynamic diameter less than 10µm (2.5-10µm) falls under the coarse particle category and is designated as PM_{10} [30]. PM of aerodynamic diameter less than 2.5µm(0.1-2.5µm) is considered as fine particle, designated by $PM_{2.5}$ [30]. The ultrafine particles are those of aerodynamic diameter less than 0.1µm represented as $PM_{0.1}$. The different size of particles can enter upto different levels in the human body. PM_{10} particles are filtered out in the proximal airway causing slight irritation in skin only [8, 30]. $PM_{2.5}$ particles enters into the peripheral airways owing to its smaller size but are stopped from entering the systemic circulation whereas $PM_{0.1}$ particles are very toxic in nature as they get introduced into the systemic circulation causing toxic effects in the body [8, 30]. Particulate matter also comprises of poisonous metals and toxic compounds like lead, barium, nickel, chromium, etc. all of which have harmful health implications [8]. The average $PM_{2.5}$ level in India is 40-50 µg/m^3 whereas the prescribed limit is of 10 µg/m^3 [7].

As the cement industry grows, the concentration of particulate matter in the atmosphere by direct as well as fugitive emissions from stocked materials increase [31]. Different procedures in cement production like, quarrying, drilling, blasting, hauling, crushing, fuel preparation, grinding of the cement clinker, packaging and transport leads to the release of particulate matter, PM_{10} and $PM_{2.5}$ [8,14,22,23,24]. Blasting of rocks produces dust particles which get distributed in the surrounding area, making it toxic [32]. Flue gases are the most usual waste released from mostly all cement manufacturing plants [29]. The cement kiln dust (CKD) which is composed of burnt, partially burnt and unburnt substances is produced during pyro-processing in the cement kiln [26,33]. The particle size of CKD ranges from 0-5µm which approximately the clay size to a size greater than 50 µm which is approximately the silt size [33]. Even though the CKD produced during the process is reused, its adverse impact is seen once it is dispersed in air [26].

Approximately 175 tons of fly ash is generated per day, of which 75 tons are from the Waste Heat Recovery (WHR) Boiler used during the calcination and clinker cooling step of cement production [29]. An average of 10 to 12 tons of bottom ash also produced daily by the cement plants [29]. The CPCB of India has formulated a specific particulate emissions limit which is equal to 250 mgNm^{-3} for the cement plants of India having a capacity of more than 200 tons per day (TPD) [23]. It is noted that a greater rigid standard of maximum 150 mgNm^{-3} was applicable for bigger plants on a case-to-case basis. After considering the above situation, the particulate concentration of the rotary kiln stack emission was found to be marginally exceeding the standard of 750 mg Nm^{-3} promulgated by CPCB [23]. As per the World Health Organization (WHO) guidelines, if we cut down the PM concentration from 70 to 20 µg/m^3, the air pollution causing death can be reduced to approximately 15% [27].

Particulate matter	Fly ash	Bottom ash	Flue gas	Dust and smoke	Silica fume
size	0.5 – 200 µm	0.1-100mm		0.05 to 10 µm	<1µm
composition	SiO_2- 47.8% Al_2O_3.24.4% Fe_2O_3- 17.4% CaO – 2.4% MgO – 1.19% Trace amounts of SO3, K_2O, Na_2O, Pb, Hg, Cr, Cd.	SiO_2-56% Al_2O_3 -26.7% Fe_2O_3-5.8% CaO- 0.8% MgO – 0.6% SO_3- 0.1% K_2O – 2.6% Na_2O-0.2% TiO_2- 1.3%	O_2- 7.5% H_2O-18.2% CO_2 – 17.8% N_2- 56.5% (rest in mg/N3) Dust-8.7 CO-1470 NOX- 250 SO2- 25 HCl- 10	Si-10.10% Ca-32% O_2-36.14% Al-1.68% Mg-0.30% Fe-1.09% S-1.73% C-10.64% Cr-0.008% Trace amounts of Hg, Cr, Co, Pb, Ni, unburnt carbon particles.	SiO_2-92.5% Al_2O_3 -0.7% Fe_2O_3-0.96% CaO- 0.4% MgO-1.7% K_2O – 0.8% Na_2O-0.5%
Step of release	Burning of coal in cement clinker	Burning process in incinerator. Clinkerization.	Production of clinker and fuel combustion	Almost at all steps like crushing and grinding of raw materials, clinkerization, calcination and packaging of final product.	Calcination, rotary kiln

Table 1: Showing few particulate matters due to cement industry, their size, chemical composition and step of release [34-41].

2.3 HEALTH IMPACTS

Particulate matter is one of the major pollutants that exceeds the National Ambient Air Quality Standard (NAAQS) according to the data from National Air Quality Programme [7]. As per the study in [42] about 18% of the total deaths in India were caused directly or indirectly due to air pollution [7]. Nationally, it is found that an increase in air pollution causes a significant drop in labour and agricultural productivity hiking the expenditure on health infrastructure in turn [7]. The workers of the cement manufacturing plants have greater exposure to particulate pollution which accelerates their chances of acquiring more of the respiratory ailments than the local people [17-20].

The particulate matter mobilizes a huge number of harmful compounds like metal oxides of iron, silicon, calcium, aluminium, magnesium, sand and other impurities which lead to occupational diseases like silicosis, bronchitis and pulmonary infections [19,31, 43, 44]. Cement dust components containing silica, chromium and alkaline substances which is capable of causing various serious pathological conditions [8,17-20, 44]. Some of them include pathogenesis of lung diseases like tuberculosis, chronic bronchitis, asthma, carcinoma of lungs, pneumoconiosis, stomach or colon disease, dermatological issues, allergy, corrosive effects, impairment of lung function, chronic obstructive lung disease, restrictive lung disease, premature deaths as well as increases mortality rate [8, 17-20,44,47-53]. Eye exposure to cement dust causes irritation leading to redness and blindness depending on the severity of exposure. Workers suffer from occupational asthma due to hexavalent chromium present in the cement [44]. As compared to adults the children suffer a more vital oxidative damage due to deposition of minute and fine particles in lungs [31]. The degraded air with differently sized particulate matter causes chronic obstructive pulmonary diseases (COPD) affecting the lifestyle of workmen and local dwellers [14,32]. The aged people and those suffering from cardiopulmonary diseases are a part of the most endangered community considering an expected exposure to $PM_{2.5}$ [14].

The particulate matter enters the respiratory tract or the gastrointestinal tract by processes like breathing, inhalation or swallowing [8]. Studies have found that short term exposure to $PM_{2.5}$ increases the risk of respiratory diseases to a great extent, owing to its ability of deeper penetration in the respiratory tract [14,8]. Lung dysplasia and squamous metaplasia in conjugation with greater frequency of respiratory symptoms and decreased ventilatory functions are known to have caused to the workers exposed to cement dust. Dysplasia in turn is said to be a precursor of squamous cell carcinoma [18,19]. Silica being an important ingredient of the cement dust leads to diseases like glomerulonephritis, vascular disease, acute silicosis, rheumatoid complications, interstitial fibrosis and also impacts the immune system [20, 45, 46]. The Central and peripheral nervous system is severely affected and the synthesis of Haemoglobin is hindered by lead and cadmium present in the cement dust. Lead on one hand affects the kidneys whereas Cadmium on the other hand shows the harmful actions on important enzymes of the body. Cadmium leads to painful osteomalacia and kidney damage. Cadmium pneumonitis featured by edema and necrosis of pulmonary epithelium happens when cadmium oxide dust and fumes are inhaled in the form of cement particulate. [17]

Harmful effects of cement dust can also be traced to the environment in the form of change of chemical composition and pH of the soil, decreasing the chlorophyl concentration of the crop. The cement dust present on the leaves interfere with the natural absorption of sunlight and exchange of gases leading to diseases like premature falling of leaves and stunted growth. All of these lead to lower productivity of crops ultimately affecting the entire food chain [8, 54].

2.4 RESOLUTION

Inevitable growth of the cement industry is observed considering the increasing infrastructural needs of the country. Since the perilous nature of the industry cannot be overlooked it becomes a responsibility to find out safety methods. Use of proper Personal Protective Equipment (PPE) in the form of helmet, earplugs, gloves, shields, clothing, masks and goggles for all the workers should be a must [25,44]. Dust generations can be reduced by watering during surface mining, wet drilling of limestone beds and lowering of power factor. Optimization of blast holes during rock blasting can reduce excessive output of flying rock. Planting of dense shrubs like *Psidium cattleianum*, *Mangifera indica* etc. can be a useful method for trapping the dust particles [25]. Alternative and less polluting fuel should be used. Various new technologies are brought forward to counter the implications of the plethoric industry. The particulate matters are channelized through a number of set-ups before releasing the emitted air into the atmosphere. The type of dust collector to be used is determined by the size of particles, quantity of moisture, rate of flow, dust loading and temperature of the gases. Special Air Pollution Control Devices (APCD) in the form of cyclones, multi-cyclones, bag filters, electronic precipitators, gravel bed filters and scrubbers are used. The raw gas is passed through filters and the clean gas exists out when passed through flexible pulse jet fabric filters. Electrostatic precipitators with 99% efficiency are used to remove dust particles with the help of electrostatic force and corona effect [13]. Unique wet scrubbers are designed where the gas is passed through a scrubbing liquid which removes the pollutants by absorbing them. Bag houses filtration technique where air is passed either way through fabric bags traps the particulate matter in the fibres. Fly ash can be removed with the help of cyclones where high velocity treatment is given to the particles. This method treatment is also backed by Selective Non-catalytic Reduction (SNCR) to remove the nitrogen oxides produced in the process. In compliance to the government regulations, the cement industries are employing various technologies to reduce the emissions. With the help of such technologies and many more new developments and computer modelling, the harmful effects of the particulate matter can be diminished and the environment saved in turn [13]

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3. CONCLUSION

The need and demand of cement is ever increasing as it is directly proportional to the developing rate of any country. The production of cement can be done in a given number of steps, each of which leads to the generation of pollutants. The negative impacts of this industry can be measured in terms of the harmful impacts it has on the human life and the environment. In spite of this the production has to go on. A number of methods to reduce the generation of particulate matters have been summarized in this review article which can be a way to bring down the level of danger to a great extent. Thus, understanding the impacts and adapting to the judicious way of resources utilization can help the cement industry to grow even more without being much of a nuisance.

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