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Indoor air quality in cement industries and potential effect on health

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Abstract

This study aimed to assess Indoor Air Quality (IAQ) in a cement production plant in terms of Particulate Matters ($PM_{2.5}$, and PM_{10}), gaseous pollutants (SO_2, NO_2, CO_2 and CO) and Total Volatile Organic Compounds (TVOCs). The obtained result revealed that the higher concentration of PM10, PM2.5, SO_2, NO_2 were measured at the clinker cooling area, while the kiln area has the higher concentration of CO_2, CO and TVOCs. Concentrations of pollutants ranged from 0.05-2.65mg/m^3, 0.012-0.121mg/m^3, 0-21ppb, 340-430ppm, 0-3ppm, 0.065- 0.215ppm and 44-122ppb for PM10, PM2.5, SO2, CO2, CO, NO2, and VOCs respectively. Control at source strategy and housekeeping are the key points in reduction of the indoor air emissions. Further studies regarding long-term effect of cement industry on the employees' health is recommended. Periodical medical check, PPE wearing, and site management will reduce the effect of indoor emissions on the health of workers.

Keywords: Cement, air quality, health, dust, gases, control.

Introduction

Cement is the second widely used substance after water where worldwide production reached about 4.2 billion tons in 2014[1,2].Cement manufacturing sector is considered as a third largest industrial source of pollution responsible for 5% of the global carbon emissions[3]. The production of one tone of cement clinker, results in 46.7g, 1.80kg, 0.504kg, 52.4g, 9.8g, and 0.7g of dust, NOx as NO_2, SO_2, VOC as C, HCl, and HF respectively[4].

Emissions from the cement industry are directly related to the compositions of the raw materials and the production method. The approximate compositions of the raw materials are: limestone (65%), silica (21%), alumina (6%), iron oxides (3.5%) in addition to the miner oxides (MgO, K_2O, Na_2O, SO_3)[5]. The raw materials are mixed with others, preheated and burned in a rotary kiln at about 1400–1500°C; the partially fused resulting is known as clinker. The clinker is then cooled and ground to a fine powder in cement mills. Finally, 5% of gypsum is added during the grinding process to provide means for controlling the setting of the cement[6,7].

Air pollution from cement industry is considered as a worldwide environmental challenge. The emissions from cement plants which got the greatest concern, and which need to be dealt with are represented by dust and gaseous emissions[8].

The main source of gaseous emissions, which include carbon oxides (CO and CO_2), nitrogen oxides (NO_x) sulfur dioxide (SO_2), and total volatile organic compounds (TVOCs), is the fuel combustion and these pollutants are emitted to the air resulting in significant deterioration of the surrounding environment[9]. Dust emissions are one of the most significant impacts of cement manufacturing process and are emitted by almost all production process such as from rocks explosion, drilling, crushing of rocks, materials' storage, clinker milling, clinker's storage, and cement packing. Waqas et al.[10] reported that the main source of particulate matters (PM_{10} and $PM_{2.5}$) are crusher and cement mill units and 80% of particulate matters samples were exceeded the national environmental quality standards.

Indoor air pollution has substantial effects on human health and may causes many occupational diseases such as allergic, asthma, and damage of the neurological, reproductive, and pulmonary systems[11]. In 2012, about 7 million people died as a result of air pollution exposure, with 4.3 million deaths were attributable to indoor air pollution[12].

Recent studies determined that pathological conditions encountered in cement industry workers include diseases of the respiratory tract, skin diseases, chest pain, irregular heartbeat, rheumatic conditions, hearing, visual disorders, and cancer[13-15]. Many studies reported a strong relationship between lung and respiratory functions and the exposure to the cement dust. The studies indicated that the workers are exposed to many health hazards at the crushing and packaging units due to the high emissions of dust at these areas[16-18]. Soussia et al.[19] found that the high dusty areas caused a significant impact on the workers eyes disorders, mainly during work times when the workers touch their eyes with their hands which are covered with cement

dust. It has been found that the personnel protective equipment (PPE) has a significant role in reducing the Hazards facing workers in the cement manufacturing industry[3,20]. Other study showed that raising awareness of workers, using PPE and using dust control measures can contribute to minimize respiratory health of the workers[21].

The impact of indoor air emissions on workers' health depends on pollution control measures in the plant, the length of exposure time, and the sensitivity of the receptor. While ambient air quality has been taken great attentions, few studies related to indoor air quality were conducted. The current study was carried out to assess the concentration of particulate matters (PM_{10} and $PM_{2.5}$), and gaseous emissions (SO_2, NO_2, CO_2, CO and TVOCs) in different operational units inside a cement plant in Saudi Arabia. Also, the emissions concentrations were compared with applicable international standards.

Methodology

This paper deals with a comprehensive survey of the main indoor air pollutants related to the cement production. The potential sources of air emissions were determined, and the measurements were taken in the most representative points.

A cement plant in Jeddah city in Saudi Arabia was selected as a case study to investigate the indoor air quality inside the cement industry. The study was conducted March 7-14, 2017. The plant is using the dry production method and the heavy fuel as a source of energy. Gaseous concentrations were measured using portable Modular Area Monitor made by Greywolf.

The instrument has two probes equipped with four sensors to measure CO, CO_2, SO_2, NO_2, and VOCs. The accuracy of the probes ranged from ± (1-4%), with high detection limit up to 0.1ppm for NO_2. For field works, rechargeable battery with active life of 18 hrs was used as a source of energy. Greywolf instruments were used successfully in many researches for monitoring of air quality[22,23].

Samples were taken every 15sec., and the average of 30 minutes of reading was reported. Grab sampling technique during three successive operation days was followed. The instrument was installed on a triangular stand at a height of approximately 1.5 m, with more than 2m away from the nearest obstacles to avoid any potential interference during sampling[24]. The particulate matters (PM_{10}, $PM_{2.5}$, TSP) were measured using dust profiler from Aeroqual. All instruments were calibrated before used.

The concentrations of pollutants were measured at ten sites including; cement mill, clinker cooling, kilns, mixing basin, kilns' control room, loading of products, the limestone quarry, coarse crushing of rocks, fine crushing of aggregates, and at the reference point. Then the results were compared with the recommend international standards.

Results and discussion

Dust level: OSHA[26] recommended a limit of 5 and 15mg/m^3 for respirable and total dust in cement plant, while UK guidelines are 4mg/m^3 and 10mg/m^3 for both parameters respectively. Although the measured dust is below these limits, this does not mean that no health effect is expected. There are clear evidences about the impact of dust on employees' health at lower concentration than the permissible level, so many agencies recommended to lowering the current guidelines limit of dust in the workplace[27]. Dust is considered the biggest cause of work-related death. It has been reported that about 4000 employees die annually due to the chronic obstructive pulmonary diseases caused by exposure to dust in the workplace[27]. Mirazaee et al. found significant increase in the cases of cough, phlegm, and dyspnea for the exposed group to cement dust in comparison with unexposed group. Also, test of pulmonary function showed reduction in the force expiratory, force vital capacity, and vital capacity of the employees exposed to dust. The measured PM10 in clinker cooling area reached more than 18 times of the ambient air quality standards (0.140mg/m^3), also, PM2.5 concentration reached more than three times of the ambient standard limit (0.035mg/m^3). This figure indicated a series health effect might be expected in case that the workers are not provided with suitable PPE or when they do not wear it. To ensure safe environment, it is the responsibility of the employer to enforce the workers for wearing their PPE, awareness training program related to the importance of PPE and the hazard of dust, implementing periodical medical check, control of dust at source, continuous monitoring, inspection checks, and conducting annual auditing shows the results of emitted particulate matters measured in this study. The concentration of particulate matters (PM_{10}) ranged from 0.05 at the Kline area to 2.65mg/m^3 at the clinker cooling area in comparison with 0.04mg/m^3 in the reference point. The function of the clinker cooling is to drop the temperature of the clinker from about 1300C about 200C by forcing air through fans. During this process dust are generated in the surrounding area which explains the high concentration of dust in this area. Kiln area and the quarry, have direct connection with the ambient atmosphere, providing mixing of pollutants which explains the lower concentration at these points. In contrast, high concentration was detected in the closed area such as in the cement mill area. It is worth to mention that the ambient concentrations of dust in the open areas depends strongly on the distribution of the production units and which one is located in the upstream or at downstream of wind. For example, if the cooling unit is located at the upstream side, it will cause high pollution to all sites and vise-versa. Also, open storage of clinkers and/or dust is the major sources of dust inside the workplace. Fine crushing generates higher dust than the coarse crushing process. Due to its weight, larger particulate in case of coarse crushing settle faster close to the source, while the finest ones generate from fine crushing stay suspend in the air for a distance.

Similarly, higher concentration of $PM_{2.5}$ was detected at the clinker cooling area, mixing basin, and at the crushing area in comparison with the reference point. The measured concentration ranged from 0.01 in the reference point to 121 µg/m^3 at the clinker cooling area.

Waqas et al.[10] analyzed the particulate matters ($PM_{2.5}$ and PM_{10}) inside the cement plant; the highest mean concentrations of PM_{10} were 1.552mg/m^3, 1.329mg/m^3, and 0.59mg/m^3 in crusher, cooler and cement mill respectively. Mirazaee et al.[25] found that the concentration of respirable dust ranged from 3.7 in the kilns to 23mg/m^3 in the crushing area, while total dust concentration was 15 and 95mg/m^3 for both sites respectively.

OSHA[26] recommended a limit of 5 and 15mg/m^3 for respirable and total dust in cement plant, while UK guidelines are 4mg/m^3 and 10mg/m^3 for both parameters respectively. Although the measured dust is below these limits, this does not mean that no health effect is expected. There are clear evidences about the impact of dust on employees' health at lower concentration than the permissible level, so many agencies recommended to lowering the current guidelines limit of dust in the workplace[27]. Dust is considered the biggest cause of work- related death. It has been reported that about 4000 employees die annually due to the chronic obstructive pulmonary diseases caused by exposure to dust in the workplace[27]. Mirazaee et al.[25] found significant increase in the cases of cough, phlegm, and dyspnea for the exposed group to cement dust in comparison with unexposed group. Also, test of pulmonary function showed reduction in the force expiratory, force vital capacity, and vital capacity of the employees exposed to dust. The measured PM_{10} in clinker cooling area reached more than 18 times of the ambient air quality standards (0.140mg/m^3), also, $PM_{2.5}$ concentration reached more than three times of the ambient standard limit (0.035mg/m^3). This figure indicated a series health effect might be expected in case that the workers are not provided with suitable PPE or when they do not wear it. To ensure safe environment, it is the responsibility of the employer to enforce the workers for wearing their PPE, awareness training program related to the importance of PPE and the hazard of dust, implementing periodical medical check, control of dust at source, continuous monitoring, inspection checks, and conducting annual auditing.

SO_2 concentration: SO_2 is one of the main air pollutants of concern, emit from combustion process. Its concentration is directly related to the sulfur content in the fuel used. Also, the raw materials might be a source of sulfur emissions, where sulfur is present in all cement raw materials with amounts 0.5 to 11g of SO_3/kg clinker[28]. High content of sulfur in the Saudi heavy fuel (>3) is the main reason of high SO_2 emission form the industrial sector. The highest SO_2 concentration was found at the clinker cooling area (21ppb) but still within the limit stated by OSHA[26], 5ppm. SO_2 was not detected in the control room, limestone quarry and the reference points. Oguntoke et al.[29] investigated the concentration of SO_2 in cement plant, the result revealed that the highest concentration was 11.6ppb in the production plant and 4.4ppb in the administration block while it was 0.1ppb in the cement mill and all were below the allowable limit for human exposure. Regarding the health effect, WHO[12] reported that low concentration of SO_2 (100ppb) caused changes in airways resistance, while higher concentration of 400ppb caused changes in resistance lung function[12]. Based on the survey result, there is no health effect related to SO_2 exposure is expected.

Carbon oxides concentrations: In cement plant, CO_2 is generated by two processes: fuel combustion as a source of energy, and the calcining of limestone or other calcareous material[30]. The concentration of CO_2 varied from 340ppm at the coarse crushing area to 430ppm in the kiln control room in comparison with 305 in the reference point. All measurements are within the normal background level; this may be due to the good mixing of indoor emissions with the ambient air during the survey period.

Unlike CO_2, CO is generated from incomplete combustion of fuel. CO is more dangerous than CO_2, and at high concentration may lead to death within a short time of exposure. Most of the absorbed CO binds with haemoglobin, which causes a gradual reduction in the oxygen-carrying capacity of the blood, subsequently lead to many health effects such as headache, dizziness, nausea and vomiting[31]. Very low concentrations of CO were measured in most sites, and the highest CO concentration was detected in the kiln area (3ppm) while the lowest was at the reference point of 0. Cement mill is a close area and there is no combustion process occurs, which explain zero concentration at such area. Crushing of fine aggregate generates high concentration of CO and CO_2.

UK regulations limited CO_2 concentration in the workplace at 15000ppm for short term exposure limit and 5000ppm for long term exposure limit[32]. WHO determined the exposure limit of CO in the workplace at 90ppm for exposure time of 15 min, 50ppm for 30 min, 25ppm for 69min, and 10ppm for 8 hours[12]. All measurements of CO and $CO_2$are far below the standard limits, and no health effect is expected.

NO_x concentrations: After CO_2 and methane, NO_2 is the third most important greenhouse gas contributes about 6% to the greenhouse gases. Cement plants are responsible to about 5%-6% of total global NOx emission with average stack's emission rate of 318-77mg/m^{333}.

In the cement manufacturing process, NO_x is generated in both the burning zone of the kiln and the burning zone of a pre-calcining vessel. The amount of NO_x generated depends on the content of nitrogen in the fuel used[30]. Table-2 showed that the NO_2 concentration ranged between 0.065ppm at coarse crushing site to 0.215ppm in the clinker cooling area. Approximately, the same level of NO_x was detected in the cement mill, kiln, control room and the mixing basin area. Although this concentration is

higher than the ambient air quality standards (0.2ppm), it is below the OSHA permissible limit in the workplace of 5ppm. Oguntoke et al.[29] reported that the NO_2 concentration ranged between 0.1–13.2ppb with the highest level in the cement mill site. At high concentration, NO_2 can irritate the lungs, eyes, airways and throat, affect infection resistance of respiratory, causing asthma and pulmonary oedema and become danger to life and health at concentration of 20ppm[34]. All measurements are very low, and no health effect is expected.

Table-1: Measured PM10, PM2.5.

Parameter / Unit	PM_{10} (mg/m^3)	$PM_{2.5}$ (mg/m^3)
Cement mill	2.15	0.026
Clinker cooling	2.65	0.121
Kilns	0.05	0.012
Mixing basin	1.55	0.084
Kilns' control room	0.24	0.021
Loading area	0.26	0.020
limestone quarry	0.18	0.012
coarse Crushing	0.22	0.019
Fine Crushing	0.25	0.070
Reference point	0.04	0.01

Table-2: Measured Results of Gaseous Pollutants.

Parameter / Unit	SO_2 (ppb)	CO_2 (ppm)	CO (ppm)	NO_2 (ppm)	TVOCs (ppb)
Cement mill	7	345	0.00	0.130	63
Clinker cooling	21	380	0.20	0.215	75
Kilns	8	350	3.00	0.165	122
Mixing basin	5	355	0.05	0.145	45
Kilns' control room	0	430	0.05	0.135	110
Loading area	2	390	1.00	0.100	45
limestone quarry	0	375	0.70	0.135	44
coarse Crushing	0	340	0.04	0.065	44
Fine Crushing	7	360	1.20	0.130	59
Reference point	0	305	0.00	0.051	43

VOCs concentrations: VOCs are organic chemicals evaporate easily at room temperature and emit from different industries especially that have fuel combustion process. In European countries, cement kilns generate about $22.8g/m^3$ of VOCs with emission rate of 52.4g/t ck[4].

From an environmental point of view, VOCs are one of the major contributors to Ozone and photochemical smog formation. Regarding health effect, some of these compounds may have short or long-term health effect. Exposure to VOCs may cause irritation to skin, nose, eyes, and respiratory system; also, they have long term negative effect on the kidney, cardiovascular, liver, gastrointestinal, and central nervous system. The concentration of VOCs ranged from 44ppb in the quarry to 122ppb at the kiln area. High concentration in the kiln area was attributed to the high fuel consumption. Also, significant concentrations were measured in the kiln's control room, mills, and clinker cooling area.

Since VOCs compounds consisting of tens of the organic compounds, there is no OSHA exposure limit for VOCs, while there are many guidelines for individual compounds such as Toluene, Methanol, Ethanol and formaldehydes. Many countries (Japan, China, Korea, Australia..) and agencies (ASHRAE, Scandinavian Heat Vent and Air Societies) set VOCs limit inside the buildings with approximated ranges of 75-500ppb[35]. Low concentrations of VOCs inside the plant indicated no health effect is expected.

Conclusion

Cement industry has high impact on the human health and the environment. This study investigated the concentration of dust and gaseous emissions inside a cement plant. The obtained results revealed that the higher concentration of SO_2, CO_2, NO_2 were measured at the clinker cooling area, while the higher CO and TVOCs were found at the kiln area. Although the concentrations of the pollutants are exceeded the ambient air quality criteria, but they are below the permissible limit at workplace. Good control of pollutants resulted in significant reduction in the concentration of emissions. Also, most of the production areas are exposed to the ambient air which decreased the concentration of pollutants in the workplace. Based on the obtained results, it is recommended to: i. Workers should be subjected to periodical check of lungs function. ii. Reduction of materials open storage especially the clinker and the alkaline dust. iii. Reduction of the active area in the quarries and the plant as much as possible. iv. Stabilize the production area with suitable materials such as cement mortar or asphalt to avoid dust resuspension. v. Long term effect of cement industry on the health of workers should be investigated.

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