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Comparative Analysis of PM_{10} Emission Rates from Controlled and Uncontrolled Cement Silos in Concrete Batching Facilities

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Abstract

This research study quantifies the PM_{10} emission rates (g/s) from cement silos in 25 concrete batching facilities for both controlled and uncontrolled scenarios by applying the USEPA AP-42 guidelines step-by-step approach. The study focuses on evaluating the potential environmental impact of cement dust fugitive emissions from 176 cement silos located in 25 concrete batching facilities in the M35 Mussafah industrial area of Abu Dhabi, UAE. Emission factors are crucial for quantifying the PM_{10} emission rates (g/s) that support developing source-specific emission estimates for areawide inventories to identify major sources of pollution that provide screening sources for compliance monitoring and air dispersion modeling. This requires data to be collected involves information on production, raw material usage, energy consumption, and process-related details, this was obtained using various methods, including field visits, surveys, and interviews with facility representatives to calculate emission rates accurately. Statistical analysis was conducted on cement consumption and emission rates for controlled and uncontrolled sources of the targeted facilities. The data shows that the average cement consumption among the facilities is approximately 88,160 (MT/yr), with a wide range of variation depending on the facility size and production rate. The emission rates from controlled sources have an average of $4.752E^{-04}$ (g/s), while the rates from uncontrolled sources average 0.6716 (g/s). The analysis shows a significant statistical relationship ($p < 0.05$) and perfect positive correlation ($r = 1$) between cement consumption and emission rates, indicating that as cement consumption increases, emission rates tend to increase as well. Furthermore, comparing the emission rates from controlled and uncontrolled scenarios. The data showed a significant difference between the two scenarios, highlighting the effectiveness of control measures in reducing PM_{10} emissions. The study's findings provide insights into the impact of cement silo emissions on air quality and the importance of implementing control measures in concrete batching facilities. The comparative analysis contributes to understanding emission sources and supports the development of pollution control strategies in the Ready-Mix industry.

Keywords

Emission Factors, Concrete Batching, Cement Dust, PM_{10}, Fugitive Emissions, Silos, Environmental Impact, Air Quality, Ready-Mix, Industrial Facilities

1. Introduction

The three main constituents of concrete productions are: aggregates (coarse and fine), water, and cement as a binder, the concrete mix design reference is Cement: 350 kg/m^3, Water content (0.52): 182 L/m^3, Sand: 857 kg/m^3, Gravel: 1007 kg/m^3. The cement consumption by concrete batching facilities during 2019 in Germany was 57%, USA 67%, and China 40% [1]. The batching plant's operations can produce considerable dust emissions, leading to its release into the surrounding environment. The common practice is storing cementitious materials in elevated silos above the designated truck loading area. Air Pollution Control Devices (APCD) should be used to control dust emissions from cement while loaded into the silos [2].

Cement silos in the Ready-Mix industry can be a remarkable contributor to air pollution through the emission of particulate matter that has a diameter of 10 micrometers or less (PM_{10}). The storage and handling of cement in these silos can generate dust, which has the potential to escape into the nearby environment, posing a health hazard to residents and workers in the surrounding area [3]. Cement dust is a finely ground, lightweight powder categorized as a highly dust-prone material once released from uncontrolled sources. It forms fugitive dust clouds that are noticed to linger in the air for several minutes [4].

The fabric filters and electrostatic precipitators are from best management practices designed to control 99.9% of PM_{10} emissions [4] [5]. The fabric filter as a filtration system, also known as a baghouse, can take the form of cylindrical fabric bags or cartridges made of different materials that are highly effective in capturing particles from a polluted gas stream by depositing the particles on fabric material with diameters ranging from submicron to several hundred microns, achieving collection efficiencies that are typically greater than 99% or 99.9% [5]. The Pollution Control Equipment Register (PCER) is necessary to record the information about pressure drops, the visual condition of exhaust material, and occurrences of filter media failure or replacement [6].

Long-term exposure to cement dust has been documented to result in an increased occurrence of chronic respiratory symptoms and a decrease in lung capacity, moreover, the absence of respiratory protection during exposure to cement dust can result in the development of obstructive respiratory impairment [7]. Despite these challenges, the Ready-Mix industry remains a vital part of the construction sector, providing essential building materials for a wide range of projects, as the demand for new infrastructure and buildings continues to grow [8]. This industry is likely to play an increasingly important role in meeting the needs of a rapidly changing world [9]. Emission factors are values used to estimate the quantity of a pollutant released into the atmosphere related to specific activities or processes [10]. They play a crucial role in assessing the environmental impact of these activities. Additionally, they are essential for developing emission inventories, which provide comprehensive data on pollutant emissions, help identify major pollution sources, and formulate effective pollution control strategies [10] [11]. Emission factor is a crucial input in air dispersion modeling to predict the dispersion of pollutants and assess their potential impacts on air quality and sensitive receptors in the specific geographical domain by estimating the emission rates that are typically in grams per second (g/s) [12].

This research intends to quantify PM_{10} emission rates (g/s) for the controlled and uncontrolled cement silos scenarios in 25 concrete batching facilities in the M35 Mussafah industrial area of Abu Dhabi, UAE applying USEPA AP-42 step-by-step approach through 1) Estimating the PM_{10} emission rates from 176 cement silos; 2) Comparing the results of controlled and uncontrolled scenarios emission rates; 3) Conducting statistical analysis for the data.

2. Materials and Methods

2.1. Study Zone Description

Mussafah is an industrial area located in Abu Dhabi, United Arab Emirates (UAE). It is known for its significant industrial and commercial activities, including manufacturing, construction, and logistics. The area is strategically located near major transportation routes, including highways and ports, facilitating the movement of goods and materials. It is home to numerous industrial complexes, warehouses, factories, and construction sites. These industrial and commercial facilities contribute to the region's economic growth but can also cause environmental concerns. Efforts have been made to regulate and manage the environmental impact of industrial activities in Mussafah to ensure compliance with air quality standards and pollution control measures. The M35 zone in Mussafah, as shown in **Figure 1**, is where the concrete batching facilities are mainly clustered. The UAE government and local authorities have implemented policies and regulations to monitor compliance with laws and regulations to ensure environmental protection along with country-wide development. The UAE government and local authorities have established policies, laws, and regulations aimed to safeguard the environment along with nationwide development.

Figure 1. M35-Mussafah-Abu Dhabi-UAE location map (Apple Maps).

2.2. Data Collection Methodology

Various data collection methods were applied in this study to gather detailed information about each concrete batching facility in M35-Mussafah, Abu Dhabi, UAE. Field visits were carried out, and data collection surveys were also distributed and discussed to ensure adequate information was collected to calculate emissions rates. Interviews were conducted with the facilities' representatives to obtain data on annual production rate, raw material usage, energy consumption, and other process-related details such as the use of additives, amount of cement stored in the silos, plant capacity, frequency of cement silos loading and unloading, and the duration of each activity. The study identified 176 silos in 25 concrete batching facilities and material handling and storage practices to calculate the PM_{10} cement emission rates using USEPA-AP 42 emission factors. The emission rates estimate accuracy depended on the data's quality and availability. Therefore, a critical assessment and quality check of the survey responses using statistical software to ensure that the data collected was robust and accurate enough.

2.3. Emissions Rates Calculations

The emissions factor is commonly described as the ratio between the weight of a pollutant and a unit weight, volume, distance, or duration of the activity releasing the pollutant, for instance, kilograms of particulate matter emitted per megagram of cement loaded. These factors enable the estimation of emissions from various sources of air pollution. Generally, these factors are averages of all available data of adequate quality and these factors are assumed to represent long-term averages for the entire population of emission sources [10].

The general equation for emissions estimation:

$$E = A \times EF \times (1 - ER/100)$$

where: E = emissions estimate, (ratio of the mass of pollutant emitted per unit of activity generating the emissions) **(Kg/yr)**.

A = activity rate is Mg cement loaded to silos per year, **(Mg/yr)**.

EF = emission factor, in Kg pollutant per Mg of cement material loaded **(Kg/Mg)**.

ER = overall emission reduction efficiency, %.

The emissions rate estimate in (Kg/yr) and converted to the amount of time over which the emissions occur in seconds is expressed in grams per second (g/s) and calculated using the following formula:

$$\text{Emission Rate (g/s)} = \text{Emissions (kg/yr)} \times 1000\ \text{(g/kg)}/(365 \times 24 \times 3600)\ \text{(s/yr)}$$

- **Emissions (kg/yr)** are the total amount of emissions in a year from the source.
- **1000 (g/kg)** is the conversion factor from kilograms to grams.
- **365 days** a year, **24 hours** a day, **3600 seconds** in an hour.

Developing emission rates inventory for the concrete batching facilities requires quantifying the emission rates for each individual cement silo in the 25 concrete batching facilities. The emission factors from US EPA-42, Fifth Edition, Volume I Chapter 11: Mineral Products Industry-11.12 Concrete Batching were used to calculate these rates. The cement silos are typically fitted with dust filters to capture any cement dust that may become airborne during cement loading activities. The filters are highly efficient in reducing PM_{10} emissions, as they can lower emissions by 99% or more when functioning and maintained properly. Nevertheless, numerous cement silo dust filters have been found to be either malfunctioning or bypassed. When the dust filter is not working appropriately, the emissions generated by the cement transfer into the silos can become exceedingly high [13] [14].

The emissions factor for the pneumatic transfer of cement to a storage silo using a bag or cartridge filter is **0.00017 kg/Mg** of cement transferred however the emissions factor for uncontrolled emissions for the pneumatic transfer of cement to a storage silo is **0.24 kg/Mg** of cement transferred. Table 1 summarizes these emissions factors [14].

3. Results and Discussion

3.1. Emission Rates Results

The emission rates for PM_{10} from 176 cement silos were estimated using US EPA-42 emission factors for controlled and uncontrolled sources. These rates were calculated based on the annual cement consumption of each concrete batching plant and the emission factors provided in the US EPA-42, 5th Edition, Volume I Chapter 11: Mineral Products Industry-11.12 Concrete Batching. The calculated emission rates for both controlled and uncontrolled scenarios, along with the annual cement consumption to assess the impact of cement dust (PM_{10}) on air quality as shown in Table 2. The two scenarios applied the same production and cement consumption data but varied in terms of the efficiency of the Air Pollution Control Devices (APCD). The APCD collects particles from 1 to 10 μm during the pneumatic cement transfer process before releasing them into the atmosphere either efficiently by 99% or not operating properly, and there was no level of control.

3.2. Data Statistical Analysis

Minitab version 19.1 is a statistical software designed for data analysis from Minitab, LLC, was used in this study to conduct statistical analysis presenting the cement consumption and emission rates from controlled and uncontrolled sources within 25 facilities. The analysis of the statistical measures shows significant differences between controlled and uncontrolled sources in terms of cement consumption and emissions as shown in Table 3, the mean value for cement consumption is 88,160 **(MT/yr)**, with a wide variation indicated by a standard deviation of 86,028 **(MT/yr)**. The total consumption across all evaluated concrete batching facilities is 2,203,993 **(MT/yr)**. Besides, the mean emission quantity for controlled sources is 14.988 **(kg/yr)**, with a standard deviation of 14.624 **(kg/yr)**. The total emissions from controlled sources amount are 374.68 **(kg/yr)**. Contrarywise, uncontrolled sources demonstrate higher mean emissions quantities of 21,158 **(kg/yr)**, with a wider range of variation of 20,647 **(kg/yr)** and significantly larger total emissions of 528,958.32 **(kg/yr)**. The large difference in emission

Table 1. The default AP 42 emission factors for cement pneumatic transfer [5] [14].

Silos Condition	Emissions Factor (kg/Mg)	Efficiency	Control Type (APCD)
Controlled	**0.00017**	99% or more	Fabric filters (bag house, cartridges filter)
Uncontrolled	**0.24**	-	Not operating properly, and there was no level of control

Table 2. Estimated PM_{10} emission rates for controlled and uncontrolled cement silos.

Facility ID	Cement Consumption (MT/yr) A	Emissions, kg/yr* (Controlled) $E = A \times EF$	Emission Rate (g/s)	Emissions, kg/yr* (Un-Controlled) $E = A \times EF$	Emission Rate (g/s)
1	10,050	1.71	0.000054176	2412.00	0.08
2	100000.00	17.00	0.000539066	24000.00	0.76
3	175000.00	29.75	0.000943366	42000.00	1.33
4	4736	0.81	0.000025530	1136.64	0.04
5	24500.00	4.17	0.000132071	5880.00	0.19
6	183664.00	31.22	0.000990071	44079.36	1.40
7	19800.00	3.37	0.000106735	4752.00	0.15
8	240000.00	40.80	0.001293760	57600.00	1.83
9	45000.00	7.65	0.000242580	10800.00	0.34
10	252000.00	42.84	0.001358447	60480.00	1.92
11	46200.00	7.85	0.000249049	11088.00	0.35
12	29,000	4.93	0.000156329	6960.00	0.22
13	49309.00	8.38	0.000265808	11834.16	0.38
14	7517	1.28	0.000040522	1804.08	0.06
15	38943.00	6.62	0.000209929	9346.32	0.30
16	24000.00	4.08	0.000129376	5760.00	0.18
17	31,300	5.32	0.000168728	7512.00	0.24
18	38220.00	6.50	0.000206031	9172.80	0.29
19	300000.00	51.00	0.001617199	72000.00	2.28
20	10886.00	1.85	0.000058683	2612.64	0.08
21	60468.00	10.28	0.000325963	14512.32	0.46
22	165,400	28.12	0.000891616	39696.00	1.26
23	84000.00	14.28	0.000452816	20160.00	0.64
24	120000.00	20.40	0.000646880	28800.00	0.91
25	144000.00	24.48	0.000776256	34560.00	1.10

*Emission rate (kg/yr) to estimate the annual emissions of cement from the silos.

quantities of cement dust (PM_{10}) indicates that the uncontrolled silos have a much greater impact on air pollution and public health compared to the controlled silos.

The data shown in Table 4, demonstrates that the average emission rate from controlled sources is $4.752E^{-04}$ **(g/s)**, with a standard deviation of $4.637E^{-04}$ **(g/s)**. The recorded rates range from a minimum of $2.553E^{-05}$ **(g/s)** to a maximum of 0.0016172 **(g/s)**. However, the uncontrolled sources' average emission rate is 0.6716 **(g/s)**, with a standard deviation of 0.65455 **(g/s)**. The recorded rates vary from a minimum of 0.04 **(g/s)** to a maximum of 2.28 **(g/s)**.

Table 3. The statistical analysis of cement consumption and emission estimates from controlled and uncontrolled silos.

Statistical Measures	Cement Consumption (MT/yr)	Emission (kg/yr)	
		Controlled Sources	Uncontrolled Sources
Facilities Numbers (N)		25	
Mean	88,160	14.988	21,158
StDev	86,028	14.624	20,647
Minimum	4736	0.81	1136.6
Maximum	300,000	51	72,000
Total	2,203,993	374.68	528,958.32

Table 4. The statistical analysis of controlled and uncontrolled sources emission rates.

Statistical Measures	Controlled Sources Emission Rates (g/s)	Uncontrolled Sources Emission rates (g/s)
Facilities Numbers (N)	25	
Mean	$4.752E^{-04}$	0.6716
StDev	$4.637E^{-04}$	0.65455
Minimum	$2.553E^{-05}$	0.04
Maximum	0.0016172	2.28

These data show a significant statistical relationship ($p < 0.05$) between Cement Consumption **(MT/yr)** and both uncontrolled and controlled emission rates (g/s) and the correlation between these variables is found to be a perfect positive correlation ($r = 1$), this indicates that as cement consumption increases in the concrete batching facility, there is a tendency for the emission rates to increase as well. These statistical measures provide essential information about the average, variability, and range of cement consumption and emission rates across the evaluated facilities. Such data is instrumental in assessing and analyzing the potential impact of these factors on air quality.

The results obtained from conducting cement emission testing at RMCC, S.T. Wooten, Carolina Mat'l, and Cheney Enterprises, concrete batching facilities are 0.0052 g/s and 0.0067 g/s. These values were associated with 99.3% and 99.2% bag filter control efficiencies, respectively. Both results exceeded the maximum value obtained from the estimates within the controlled sources examined in this study, which was 0.0016172 g/s [15]. Additionally, another study conducted in 2019 focused on monitoring the concentrations of fugitive dust emitted from various processes in five concrete batching facilities the average emission rate of PM_{10} from cement loading activities was found to be $9E^{-04}$ (g/s). This emission rate is higher than the average emission rate estimated from controlled sources in this study, which is $4.752E^{-04}$ (g/s). However, it is lower than the emission rate from uncontrolled silos, which was estimated at 0.6716 (g/s) [16]. The results suggest that cement loading activities contribute significantly to the emission of PM_{10} in the studied concrete batching facilities, particularly if efficient control measures are not applied.

4. Conclusions

Emission factors comparison of emissions rates between different controlled and uncontrolled sources provided a standardized approach for evaluating the environmental performance and impact of different scenarios, helping identify the most environmentally friendly alternatives and develop pollution control and mitigation strategies. Understanding the emission factors associated with specific activities makes it possible to identify areas for improvement and implement measures to reduce emissions. These findings emphasize the significance of adopting measures and strategies to control fugitive dust emissions, specifically from uncontrolled sources such as: 1) installing efficient dust collection systems on cement silos using an efficient fabric filter that includes a fabric cleaning device. 2) Regular maintenance in accordance with the manufacturer's recommendations by cleaning the silos, repairing leaks, and replacing worn or damaged parts. 3) Track the pollution control equipment using PCER on a weekly basis. 4) Install high-level audio and visual alarms and an automatic delivery shutdown mechanism to prevent overfilling and subsequent damage to the filters. These alarms should have a test circuit and must be regularly tested and documented in the PCER. It is essential to ensure that every alarm apparatus is regularly maintained. 5) Train and educate workers on proper handling and storing cement and aggregates by using appropriate equipment and techniques to minimize dust generation and ensuring that workers understand the importance of controlling emissions.

These recommendations for managing PM_{10} emissions and establishing comprehensive practices for PM_{10} emission management practices are crucial to decrease the potential environmental and health effects related to PM_{10} pollution originating from cement silos in concrete batching facilities. Furthermore, proper filling of the silo without excessive product loss is necessary to establish a controlled airflow within the silo. This restricted airflow allows the cement to be collected by the filters, which then falls back into the silo and can be reclaimed for further use. The actual cost savings resulting from this product recovery process can vary and depend on factors such as the silo capacity, the quantity of cement in the silo, and the efficiency of the APCD.

Overall, the ready-mix industry has the potential to generate pollution from multiple sources, and it is essential for industry operators to implement appropriate measures to minimize their impact on the environment and public health, minimizing PM_{10} emissions is essential to protect the health of nearby residents and workers and to reduce the industry's impact on the environment. It's recommended that the findings of this study be used as foundational data for assessing the environmental impact of the PM_{10} from cement silos on the sensitive receptors in different geographical scales using air dispersion modeling and similar studies can be done to identify attainment and nonattainment areas since emission factors are used to quantify the expected levels of pollutant concentrations based on the emissions from different sources within a specific geographical region.

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Conflicts of Interest

The authors have no conflicts of interest to disclose regarding the publication of this paper.

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