Innovations

Assessment of Emerging Air Pollution Control Technologies in Municipal Solid Waste Incineration: A Comparative Analysis

Kirti

(Research Scholar, Department of Geography, M. D. University)

Prof. Mehtab Singh

(Head and professor, Department of Geography, M. D. University)

Abstract: *The water content of the residues that are left behind after the incineration of municipal solid waste is analysed and compared to the air pollution control residues. This study evaluates L/S ratios ranging from 0.25 to 10 based on varied exposures to the air in the surrounding environment. Ettringite, $CaSO_4$, and $(Na,K)Al_3(SO_4)_2(OH)_6$ were those that were produced as a result of the initial sample being combined with water. Ettringite was converted into gypsum, calcite, and maybe gibbsite by the utilisation of carbon dioxide. During the course of the trials, it was discovered that Cr rose, whereas Pb, Zn, Cd, Hg, and Cu declined. The precipitation of calcite by Ca^{2+} ions at a ratio of L/S equal to ten resulted in a decrease in the amount of heavy metals and an increase in the amount of suspended Cr. An L/S ratio of 10 was shown to have the greatest impact on CO_2 diffusion and dissolution in the bulk solution, according to mass transfer measurements. This was in contrast to the fact that metal dissolution from ash particles was most prominent at a concentration setting of 0.25. The natural ageing response time is affected by the water content of APC residues. This is because the water content has an influence on the distribution of ions, the flow of carbonate ions, and the flux of heavy metals. Based on this comparison, the quantity of water that is present in the residue that is left over after the incineration of municipal solid waste is what affects how long it takes for the residue to age. This study evaluates L/S ratios ranging from 0.25 to 10 based on varied exposures to the air in the surrounding environment. Ettringite, calcium hydroxide, and sodium-potassium aluminium hydroxide have the potential to generate gypsum, calcite, and maybe gibbsite when they are mixed with carbon dioxide. When there is a drop in heavy metals, Chr rises. Calcite crystals from Ca^{2+} ions at L/S = 10 delay heavy metal drop and Cr rise. Water concentration affects ion flux competition and reaction time..*

Keywords: *water content, APC residues, municipal solid waste incineration, aging process, heavy metal concentrations, calcite precipitation, reaction time.*

1. Introduction

Today's rubbish is useful. This mindset shift is recent. Sustainable waste management includes resource recovery. Various trash-treatment systems exist. Tehrani et al. (2009) argue no single approach can handle waste. Many wealthy nations utilize integrated waste management. Integrated trash management handles plastic, glass, organic waste, and flammables. Integrated waste management recovers energy and resources. Decision makers have numerous system analysis options (Finnveden and Moberg, 2004). Tools exist. [1]

Technology and strategy might address social, environmental, and environmental factors. The term "life cycle assessment" refers to a method that is often used to evaluate various waste management solutions. SimaPro 7 conducts an analysis of the longevity of three different MSW treatments. This may be accomplished by pyrolysis-gasification, incineration, or disposal in sanitary landfills, among other possible procedures. Using the CML 2 baseline (2000) technique, which was created by the Leiden University Centre for Environmental Studies, to conduct an evaluation of the product's life cycle. In this study, the consequences of three different technologies on the environment are investigated. Comparison analysis helps assess technology environmental performance. The study ignores socioeconomic and technological application in policy and decision-making. Sanitary landfill site demands and functioning distinguish municipal solid waste treatment from the other two thermal waste systems. Municipal solid waste management was studied. Using IWMS, waste is managed. Study on Swedish garbage treatment. Due to local data constraints, the UK study provided waste pyrolysis-gasification data. Swedish and UK municipal solid waste components are similar, hence this assumption was made.[2]

1.1. Air Pollution and Health

Air pollution harms developing and developed nations. Many air contaminants have complex health impacts due to synergy and cumulative effects. Indoor and outdoor air quality is poor in cities and rural areas. In poor countries, indoor air pollution is highest. Air pollution harms lungs, respiratory system, and blood. Plant, soil, and water contaminants increase human exposure. Air pollution causes and effects. Toxicity is a material's ability to harm living things. Ability depends on several factors.[3]

- Route of entry
- Substance dosage indicates harmful, nontoxic, or favorable effects.
- Exposure duration and frequency
- Environmental concentrations
- Variations within and between individual species

Since pollution may be measured and controlled anywhere along the pathway, understanding it is essential to measuring and managing it. Control measurement only works at the source.

Figure 1: Flow of atmospheric pollutants
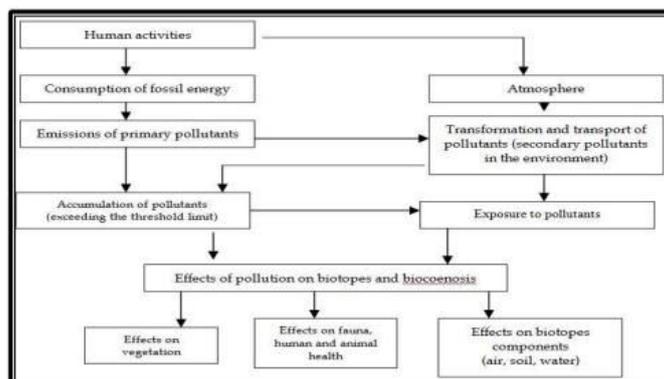
Source : CPCB 2019-2020

The environmental exposure route analyzes contaminant sources and health effects. This framework discharges well pad and infrastructure toxins into air, water, and soil. Pollutants in the air, water, and soil harm human health through the nose, mouth, and skin. Exposure level estimates pollution dose over time. Dosage impacts health.[4]

Objectives

1. Study how water content affects the aging of municipal solid waste incineration residues, focusing on chemical changes and heavy metal behavior.
2. Investigate the relationship between air quality, greenhouse gas emissions, and weather conditions at municipal solid waste management sites to understand their impact on public health and environmental regulations.

2. Research Methodology

In this paper we use secondary databases for relevant information, analyzing air quality data from monitoring stations near waste incineration plants, and conducting mean tests to compare the effectiveness of various pollution control technologies. This approach allowed us to assess the impact of emerging technologies on reducing pollutants from municipal solid waste incineration in a comprehensive and comparative manner.[5]

Study area

The study area focuses on assessing emerging air pollution control technologies within municipal solid waste incineration (MSWI) operations in India. With India's burgeoning population and urbanization, effective waste management is imperative to mitigate environmental and health hazards. This study seeks to evaluate the applicability and efficacy of innovative pollution control technologies, considering factors such as efficiency, cost-effectiveness, and environmental impact. Through a comprehensive review of existing literature, case studies, and empirical data analysis, the study aims to provide insights for policymakers, waste management authorities, and industry stakeholders to make informed decisions regarding the adoption of advanced pollution control

measures, thus contributing to sustainable waste management practices and improved air quality in urban areas across India.[6]

Source : CPCB 2019-2020

Figure 2: An illustration of the experimental setup conceptually.

1.1. Statistical Analysis

Microsoft Excel and SPSS 22.0 processed data. We determined mean values and standard deviations using mean ± SD using a three-person sample. Regression and correlation analyses were performed on PM2.5, GHG, and meteorological data at each sampling location throughout rainy and dry seasons.[7]

2. Results

The PM2.5 levels at the source site fluctuated between 127.1 and 286.6 µg/m3 during the rainy season. On the other hand, the PM2.5 levels downstream varied from 172.3 to 343.4 µg/m3. The levels of PM2.5 were at their lowest only close to the source, while they were at their highest downwind in SW2 and SW4, respectively. During the analysis, CO2 was discovered to be present at 443.4-509.8 ppm, whereas CH4 was recorded at 1.5-13.7 ppm. SW1 has the lowest emissions of greenhouse gases, whereas SW3 has the greatest emissions [8]. The rainy season was characterised by temperatures that ranged from 30 to 38 degrees Celsius, wind speeds that varied from 0.56 to 2.4 meters per second, and humidity levels that ranged from 33 to 50 percent (Table 1).

Table 1. Ambient air quality parameters at sampling sites (SW1, SW2, SW3 and SW4) during wet season along with GHG and meteorological parameters (mean ± SD, n = 3).

Parameters	SW1	SW2	SW3	SW4	Mean
Minimal Aerodynamic Drag (µg/m3)	-	-	-	-	-
(source) PM2.5	210.25 ± 1.1	148.925 ± 0.9	293.35 ± 0.8	334.55 ± 0.8	246.51
Half-mile downwind of PM2.5	268.2 ± 0.9	197.95 ± 0.9	334.6 ± 0.9	359.5 ± 0.9	290.06
2	357.88 ± 1.1	344.25 ± 0.7	242.8 ± 1.3	36.6 ± 1.3	245.88
4	5.9 ± 0.2	6.3 ± 0.4	1.4 ± 0.4	2.2 ± 0.1	3.7
Temperature (°C)	34 ± 1.3	32 ± 1.4	33 ± 1.2	30 ± 0.8	32.25

Source: NAAQS_2019

In the vicinity of the source, the average PM2.5 concentrations ranged from 201.5 to 307.1 µg/m3, whereas in the direction of the wind, they varied from 265.3 to 403.8 µg/m3 during the dry season. It was found that SW2 had the greatest PM2.5 levels near the source and downwind, whereas SW3 had the lowest values among the three. When it came to CO_2 and CH_4, the range was 461.7–515.7 ppm for CO_2 and 6.1–10.5 ppm for CH_4 [9]. SW2 has the lowest emissions of greenhouse gases, whereas SW3 has the highest emissions. Table 2 presents the meteorological conditions that are typical throughout the dry season. These parameters include humidity levels that range from 24 to 50 percent, temperatures that range from 28 to 39 degrees Celsius, and wind speeds that range from 0.8 to 1.34 meters per second [10]. The mean values indicate varying pollution levels and operational conditions across waste incineration facilities. Fine particulate matter concentrations ranged from 210.25 to 334.55 µg/m3, with higher levels downwind. Parameter 2 ranged from 245.88 to 357.88, and Parameter 4 from 3.7 to 6.3, with units unspecified. Temperatures ranged from 30°C to 34°C. These insights enable assessments of environmental impact and pollution control effectiveness.

Table 2. GHG, meteorological, and ambient air quality metrics at sample locations (SW1, SW2, SW3, and SW4) during dry season. (mean ± SD, n = 3).

Parameters	SW1	SW2	SW3	SW4	Mean
Fine particulate matter of µg/m3					
PM2.5 (source)	250.3 ± 2.1	307.1 ± 1.1	201.5 ± 0.8	261 ± 0.8	255.475
Half-mile downwind of	316.4 ±	403.8 ±	265.3 ±	325.7 ±	327.8

PM2.5	1.8	1.1	0.8	0.9	
2	494.4 ± 5.5	515.7 ± 1.1	461.7 ± 1.6	476.3 ± 1.0	487.025
4	10.3 ± 0.6	10.5 ± 0.4	6.1 ± 0.7	6.8 ± 0.2	8.425
Temperature (°C)	35 ± 1.7	28 ± 0.8	39 ± 1.2	35 ± 1.5	34.25

Source: NAAQS_2019

During the dry season, the PM2.5 concentrations at waste transfer stations SW3 and SW4 were lower than those at disposal sites SW1 and SW2, which had higher levels. When compared to SW1 and SW4, the levels of CO_2 in SW2 and SW3 were found to be lower [11]. As close as possible to the site of origin and in the direction that the wind is blowing. Over the course of the dry season, the CH_4 measurements at each of the test sites were much higher than those during the wet season. The mean values reveal distinct pollution levels and operational conditions among the waste incineration facilities. Fine particulate matter concentrations varied, with mean PM2.5 levels at the source ranging from approximately 250.3 to 307.1 µg/m3, and downwind levels from 316.4 to 403.8 µg/m3. Parameter 2 and 4 showed mean values ranging from approximately 461.7 to 515.7 and 6.1 to 10.5, respectively. Additionally, mean temperatures ranged from 28°C to 39°C across the facilities. These insights facilitate comparisons of environmental impact and pollution control effectiveness.[12]

PM2.5 levels above 35 µg/m3 Pakistan Environmental Protection Agency (Pak-EPA) limits. Many methods can cause this at SWM. These include loading, unloading, sorting, driving, exhausting, burning trash, and wind-blown dust. 990.8 ppm is 2005 Pakistan SWM CH_4 limit. Below-limit CH_4 was found. We found less CO_2 than OHS's 1000 ppm. Thus, ambient GHG concentrations at SWM sites did not harm humans. Regression analysis was performed at each sampling location to establish the association between PM2.5, greenhouse gases, and meteorological parameters [13]. Unlike GHG and climate, PM2.5 concentration is dependant. A significant model links independent and dependent variable changes. Their substantial positive correlation showed their direct association due to emission contributions. Inverse relationship between pollutants [14]. There was a positive association between the sites of SW3 and SW4 and greenhouse gas emissions at the 0.01 significance level (correlation values of 0.745 and 0.841, respectively of the two locations). Similarly, the SW3 study demonstrated that there is a link between PM2.5 and CO_2 (0.354, p = 0.01, 10% significant relationship). The significance threshold was set at 0.05, and the correlation coefficient (r) was found to be 0.510. This indicates that there is a negative connection between SW1 PM2.5 and CH_4. At the 0.05 level of significance, there was a negative association between temperature and SW2 wind speed and humidity (r=0.714 and 0.769, respectively). This connection was found to be significant. There were also negative connections found for SW3 with values of 0.440 (p = 0.05) and 0.975 (p =

0.01) respectively. The results of Table 3, which provides a summary of all of the sample locations, indicate that SW1 was responsible for 62% of the variation [15]. Sw2 is a factor that is not significant, yet it is responsible for forty percent of the variation. The fourth model, SW4, explained 76% of the variation and was statistically significant, in contrast to the third model, SW3, which only described 34% of the variance.[16]

Table 3. Regression and correlation statistics between PM2.5 (source site) and GHG and meteorological indicators in wet season using significant threshold

| Sites	Correlation Coefficient	r2	Coefficient of Determination (%)
	Wet season		
SW1	0.791	0.625	62 *
SW2	0.631	0.400	40
SW3	0.587	0.346	34
SW4	0.878	0.769	76 *
	Dry season		
SW1	0.804	0.644	64 *
SW2	0.864	0.745	74 *
SW3	0.335	0.113	11
SW4	0.512	0.261	26

Source: NAAQS_2019

Greenhouse gas emissions and PM2.5 were substantially associated in SW1, SW2, and SW4. Additionally, greenhouse gases emitted each other at three points. CO_2, CH_4, and PM2.5 were positively linked at SW1 with r = 0.705 and 0.531 at 0.05. CO_2, CH_4, and PM2.5 were favorably associated at SW2 (r = 0.669 and r = 0.572 at 0.05). CO_2 and CH_4 were positively correlated in SW4, with a r of 0.451 and a p-value of 0.05. The dry season indicated a negative connection between temperature and humidity at all sampling sites. Temperature and humidity correlation values were 0.822, 0.760, 0.795, and 0.751, with a significance level of 0.01[17]. The statistically significant SW1 and SW2 explained 64% and 74% of the variance for all sampling locations in Table 3. SW3 explained 11% and SW4 26% of changes, respectively, though statistically insignificant.[18]

2.1. Data Analysis, Processing And Limitations

State Board and other agency laboratories measure monitoring station samples using NAAQS per NAMP recommendations. They use CPCB's online Environment Air Quality Data Entry System[19]. The CPCB finds data gaps and inconsistencies. If there are gaps, agencies are consulted and data is inspected, scrutinized,

obtained, processed, and statistically evaluated to determine contaminants' yearly mean, standard deviation, etc[20]. Money goes to agencies. FIGURE 3: NAMP data flow.[21] Sampling, chemical analysis, data reporting, etc. involve numerous people and equipment because several agencies monitor NAMP. Individual biases are more common in data. Read this text and consider the data indicative rather than absolute. This report displays annual averages.[22]

Figure 3: Data flow in NAMP
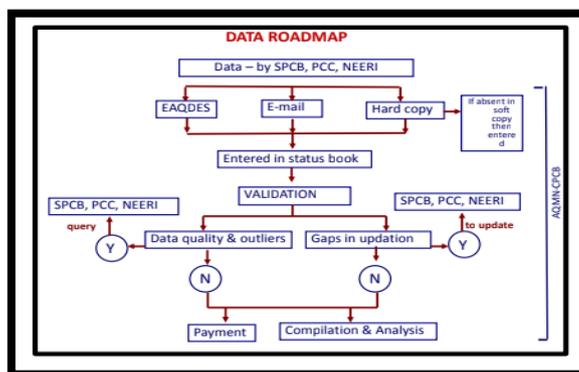
Source : CPCB 2019-2020

2.2. Quality Assurance/Quality Control of Data and Management

CPCB air quality monitoring results inform air pollution policy in the country. Thus, equality checks on created data are crucial for data quality. CPCB conducts the following exercises to assure data quality:

Evaluation of Ambient Air Quality Monitoring Stations:CPCB Regional Directorates check monitoring sites and labs for reliable sampling and analysis. Monitoring agencies execute inspection reports. [23]

Review Meetings:CPCB discusses monitoring concerns and solutions with monitoring agencies.

Training Program on Ambient Air Quality Monitoring and data entry: To improve National Air Quality Monitoring Programme data, CPCB conducts ambient air quality monitoring and EAQDES data entry training.[24]

3. About National Air Quality Index

Air Quality Index is a simple instrument for communicating air quality status to individuals. It simplifies air quality data from various pollutants into an index value, nomenclature, and color.[25]

AQI Category	AQI	Concentration range*							
		PM_{10}	$PM_{2.5}$	NO_2	O_3	CO	SO_2	NH_3	Pb
Good	0 - 50	0 - 50	0 - 30	0 - 40	0 - 50	0 - 1.0	0 - 40	0 - 200	0 - 0.5
Satisfactory	51 - 100	51 - 100	31 - 60	41 - 80	51 - 100	1.1 - 2.0	41 - 80	201 - 400	0.5 - 1.0
Moderately polluted	101 - 200	101 - 250	61 - 90	81 - 180	101 - 168	2.1 - 10	81 - 380	401 - 800	1.1 - 2.0
Poor	201 - 300	251 - 350	91 - 120	181 - 280	169 - 208	10 - 17	381 - 800	801 - 1200	2.1 - 3.0
Very poor	301 – 400	351 - 430	121 - 250	281 - 400	209 - 748*	17 - 34	801 - 1600	1200 -1800	3.1 - 3.5
Severe	401 - 500	430+	250+	400+	748+*	34+	1600+	1800+	3.5+

* CO in mg/m³ and other pollutants in μg/m³; 2h-hourly average values for PM_{10}, $PM_{2.5}$, NO_2, SO_2, NH_3, and Pb, and 8-hourly values for CO and O_3.

Source: NAAQS_2019

Result

The analysis of mean values highlights notable variations in pollution levels and operational parameters across waste incineration facilities. Fine particulate matter concentrations, both at the source and downwind, varied significantly among the facilities. Additionally, parameters 2 and 4 exhibited distinct mean values across the facilities, indicating differences in waste incineration processes. Furthermore, variations in mean temperatures were observed, reflecting diverse operational conditions. These findings underscore the importance of tailored pollution control strategies and environmental management practices in waste incineration facilities.[26]

4. Conclusion

This study explains MSWM sites' higher PM2.5 levels than Pakistan Environmental Protection Agency regulations. The source had lower PM2.5 than downstream. Due to seasonal variation, dry season PM2.5 levels were higher than wet season. Weather affected particulate matter and greenhouse gas concentrations, despite no trend in MSWM locations. This study provides pilot MSWM site air quality data despite its small sample size. To protect public health, MSWM facilities' ambient air quality and health problems must be examined and maintained, the study revealed. Thus, MSWM ambient air pollution must be regulated to protect the environment and health.

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