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Original Article

Mitigation of Methane Emissions from Domestic Waste Through Overlaying Method: A Research Investigation

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***Abstract -** Methane emissions from domestic waste significantly contribute to global warming, making it crucial to find effective mitigation strategies. This study investigates the reduction of methane emissions from domestic waste using an overlay method with different substances: Sodium Sulfate solution, Zeolite, Biochar, and Compost. A custom-built sensing device with an MQ4 sensor was used to measure gas levels. Zeolite proved most effective, reducing methane emissions from 0.007367 ppm to 0.006588 ppm. Biochar, however, increased emissions from 0.00736 ppm to 0.00821 ppm. While Sodium Sulfate reduced Methane, it produced Sodium Sulphide, which, when reacted with moisture, produces Hydrogen Sulphide, as a byproduct. Compost also showed slight reductions. Scaling up this study with additional materials and varying concentrations could offer a more comprehensive solution to methane emissions from domestic waste.*

***Keywords** - Methane, MQ4 sensor, Zeolite, Domestic garbage.*

1. Introduction

The rising urgency to address increasing methane emissions has prompted multiple innovative mitigation strategies. Effective waste management solutions are needed as rapid urbanization continues to aggravate environmental challenges. The population of India's cities increased by 543% between 1960 and 2024 as a result of widespread urbanization [1]. A survey conducted by the International Trade Administration in 2023 predicted that by 2030, due to the increased urban population, the amount of waste produced annually in India will increase from 62 million tonnes to 165 million tonnes [2]. Domestic waste presents serious threats to the environment and public health since it is frequently left uncollected next to roads and streets. It contains waste from cooking and cleaning tasks around the house and is frequently combined with medical waste. Door-to-door pickup is uncommon, and trash kinds are typically not separated, which results in ineffective garbage management. Food, plastic, wood, and toxic materials are among the waste types. Food waste is a major issue since many nations have difficulty managing it, and it increases as the world's population does. Furthermore, in developing nations, treating domestic wastewater is expensive and frequently insufficient. A large amount of waste is stored and treated in and around Landfills. Here, the waste is stored in two forms: open dump sites, where waste is stacked up on each other and in dump sites, where waste is buried underground. This process has been the most used and convenient method for disposing of waste because of its ease of implementation along with minimal operational requirements. The Environmental Protection Agency of the US has confirmed the release of dangerous gasses like Carbon monoxide, Methane and sulfur gas from dump sites [3]. Hence, it is imperative to find an alternative to landfills and reduce the emission levels. Methane is a more hazardous greenhouse gas as compared to carbon dioxide and is approximately 80 times more harmful than it [4]. Direct exposure to Methane can also lead to mood changes, headaches, nausea, vomiting, eye problems and even memory loss in severe cases. In many parts around the world, a lot of efforts are being made to reduce methane emissions. For instance, in Sweden, around 160,000 metric tonnes of food waste was diverted from landfills to produce energy and biogas [5], which helped reduce the waste in landfills and reduced emissions. In various places like Ostend in Belgium and Beijing in China, Waste to Energy models are being implemented which are helping in skipping the process of decomposition of waste and removal of gasses. A study conducted by Wassmann et al. [6] in 1991 discusses the methane emissions released from rice paddy fields and suggests methods to reduce emissions. The study suggests improving nutrient-water management, enhancing methane oxidation, and selecting rice cultivators with lower methane transport capabilities. Another study conducted by Stern et al. [7] in Florida used a biocover of 15 cm of pre-composted yard waste to mitigate methane emissions. This happened because of the increased moisture-holding capacity and increased oxidation of Methane. A recent study published in the National Library of Medicine Journal (2023) showed that methanotrophic bacterium can be used to remove Methane from the atmosphere [8]. Although bacterial seeding has shown good potential in reducing methane emissions, this application is not economically feasible and maintaining optimum growth conditions is a difficult task. To find a solution to mitigate methane emissions, which is both economically feasible and easily accessible in every region, the current study investigated the ability of sodium sulfate, zeolite, biochar and compost overlaying as an intervention to reduce the emission of Methane released from domestic waste.

2. Materials and Methods

2.1. Materials Used

2.1.1. Sodium Sulphate (Na_2SO_4)

Sodium Sulphate Anhydrous (LR grade with 99% purity) was purchased from Nice Chemicals (P) Limited Company from a local chemical shop in Delhi. One Molar solution of Na2SO4 was prepared by dissolving 142.05 grams of sodium Sulfate powder in 1 liter of water.

2.1.2. Vermicompost

Ugaoo Vermicompost was procured from Amazon. The compost was 100% organic and nutrient-rich, with appropriate proportions of NPK, sulphur, calcium, magnesium, and iron. It also contains micronutrients like manganese, zinc, copper, boron, and molybdenum.

2.1.3. Biochar

Casa de Amor Biochar (900-gram packet) was procured from Amazon. Ambika Biotech manufactured it. It contained 40% pure carbon, which had been obtained by burning biomass like corn cob, husk, wheat, and rice straw in the absence of oxygen.

2.1.4. Zeolites

High-quality industrial-grade Zeolite powder was purchased from Akshar Chem. It is usually used for water purification and air quality enhancement for a healthier environment.

2.1.5. Raspberry Pi

It was bought from the official Raspberry website. The MQ4 gas sensor was bought from Robu, and the Xiaomi power bank from Amazon. Adafruit MCP 3008 was brought from Robu. as well.

2.1.6. Domestic Waste

It was simulated using biodegradable wastes like fruit and vegetable peels, dried leaves, paper waste, and non-biodegradable wastes like plastic bags.

2.2. Assembly of Gas Detection Model

The gas detection module was built with the sensor box, Raspberry Pi Model 4B, MQ4 Methane Sensor, 10000 mAh lightweight battery bank, Airtel MyWifi Hotspot, and Adafruit MCP3008. As illustrated in Figure 1, the MQ4 sensor is linked to the Raspberry Pi and MCP3008 to create the sensing model. Raspberry Pi has been programmed to send data to Thingspeak.com's public channel, which is then linked to the HTML page online. An HTML page was connected to a domain.

2.3. Procedure for Domestic Waste Simulation

For the interventions, approximately 40 kg of residential garbage with a composition comparable to that of a landfill site was collected. It contained both biodegradable and non-biodegradable wastes. The biodegradable garbage comprised fruit and vegetable peels, as well as dry yard leaves. Similarly, the non-biodegradable content included single-use plastic bags, chip packets, and so on.

This waste was collected two weeks before the experiments, allowing the process of waste decomposition and gas emissions to commence. For the experiment, the garbage was split into 5 kg bags, which could then be overlaid with various compounds for interventions.

2.4. Procedure for Testing the Sensor for Methane Detection

A sensor gadget was built to collect readings. This IoT device consists of a methane sensor (MQ4) and a Raspberry Pi. It was developed in Python and HTML to communicate all gathered readings, as well as live data, to the thingSpeak IoT platform. The data from the thingSpeak platform is uploaded directly onto the website [9].

The internet allows for easy monitoring of any data. For one of the interventions, two dustbins with similar solid waste composition were used. Each garbage bin has an initial methane emission reading (0 reading). The waste material was then covered with compost, zeolite, sodium sulfate solution, and biochar. Methane emissions were measured at intervals of 60, 120, 240, and 360 minutes.

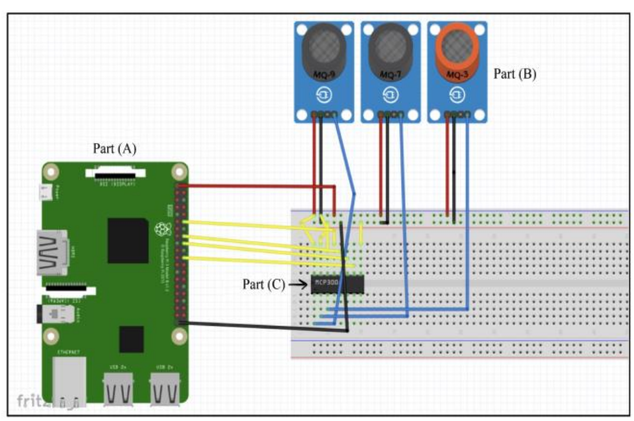

Fig. 1 This is the circuit diagram of the sensor box. Part (A) is Raspberry Pi Model B4, Part (B) represents the 3 sensors and Part (C) is MCP 3008.

3. Results and Discussion

Table 1. Values of Methane Concentration along with Time intervals of the following interventions. Key: CC- Compost (Control), CE- Compost (Experiment), BC- Biochar (Control), BE- Biochar (Experiment), ZC- Zeolite (Control), ZE- Zeolite (Experiment), SSC- Sodium Sulphate (Control), SSE- Sodium Sulphate (Experiment)

Time (mins)	Methane concentration (ppm)							
	CC	CE	BC	BE	ZC	ZE	SSC	SSE
0	0.00914	0.006588	0.000457	0.00045	0.004635	0.005226	0.004441	0.0051186
60	0.006588	0.004635	0.0137	0.00658	0.01125	0.010136	0.003172	0.00317
120	0.018283	0.012448	0.00587	0.01665	0.01244	0.008218	0.00181	0.00156
240	0.004098	0.005226	0.00463	0.005226	0.01043	0.007328	0.002172	0.00322
360	0.02193	0.02004	0.00736	0.00821	0.007367	0.006588	0.004004	0.00288

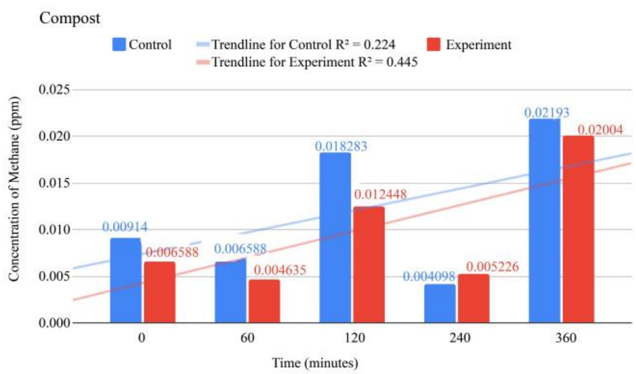

Fig. 2 Methane Emission Trends (0-360 mins) from Compost Overlaid Domestic Waste

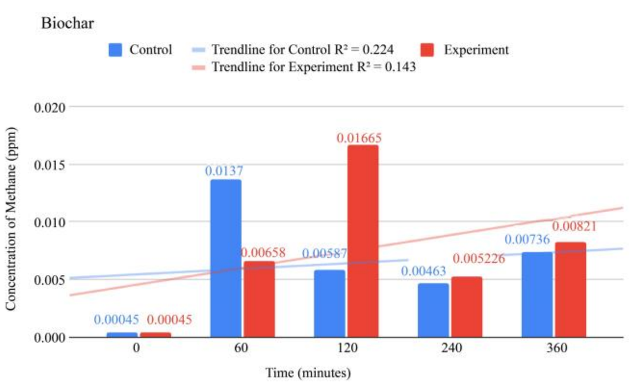

Fig. 3 Methane Emission Trends (0-360 mins) from Biochar Overlaid Domestic Waste

Figure 2 shows that methane emissions are reduced with time from 0 to 360 minutes in the compost-overlayed domestic garbage, demonstrating that the compost layer effectively suppresses methane production. The 0-minute readings for the control and experimental dustbins were 0.009 and 0.006 ppm, respectively. Table 1 shows the methane emission levels from 60 to 360 minutes. Emissions increased dramatically in the control dustbin, whereas methane levels decreased in the compost-overlaid dustbin. At 240 minutes, both the control and compost-overlaid dustbins show a significant drop in methane concentration. Initially, methane levels are higher, most likely due to the active decomposition of organic waste. However, as the compost settles and creates a more aerobic environment, the rate of methane production declines [10]. This shows that the compost layer not only acts as a physical barrier but also promotes fewer favorable conditions for methane-producing anaerobic bacteria, resulting in lower overall emissions over time. From Table 1, it can be seen that the methane emissions in the experimental setup are lower than those in the control setup at some intervals. For example, at 60 minutes, the experimental setup had a methane emission of 0.00658, while the control setup had only 0.0137. Similarly, at the 240-minute interval, the methane emission in the experimental setup was 0.005226, slightly higher than the control setup's emission of 0.00463.

However, at 120 minutes, the experimental setup showed a significant increase in methane emissions, recording 0.01665 compared to 0.00587 in the control setup. A similar increase can also be observed at the 360-minute interval, where the experimental setup showed emissions of 0.00821 ppm, which is slightly higher than the control setup's emissions of 0.00736 ppm. Theoretically, biochar is supposed to reduce methane emissions from domestic waste by adsorbing gasses due to its highly porous structure [11]. Biochar is also said to alter the microbial balance within the waste by reducing the availability of Carbon sources for methanogenesis and enhancing Carbon sequestration [11].

However, all these factors can not be very clearly observed in this intervention. For this experiment, the use of biochar has not reduced Methane emissions, and this might be because of various factors like reduced effectiveness of the type of biochar used, varying environmental conditions like increased moisture content, temperature, etc, and small scaled nature of the experiment. From Table 1, it can be seen that the methane emissions in the experimental setup are generally lower than those in the control setup in most of the time intervals. At the intervals of 60 and 120 minutes, the emissions from the experimental setup were lower than those of the control setup. Reductions are also noticeable at the 240-minute interval, where the experimental setup emitted 0.007328 ppm, while the control setup showed a higher emission of 0.01043 ppm. At the 360-minute mark, the trend continues, with the experimental setup showing an emission of 0.006588 ppm compared to 0.007367 ppm in the control setup. There are many theoretical reasons for the decrease in methane emissions over the period of 60, 120, 240, and 360 minutes.

Zeolite usually has a very porous structure, which enhances the adsorption of gasses around it, including methane [12]. Also, its strong ability to exchange cations in structures can alter the ionic balance of the methanogenic bacteria present in the waste [13] [14]. It also acts as a catalyst to speed up the process of waste decomposition in such a way as to reduce the emission of gasses like Methane. All these might be the reasons for the decrease in methane emissions over the period of 60, 120, 240, and 360 minutes. Thus, zeolite seems to be effective for the reduction of methane emissions from domestic waste.

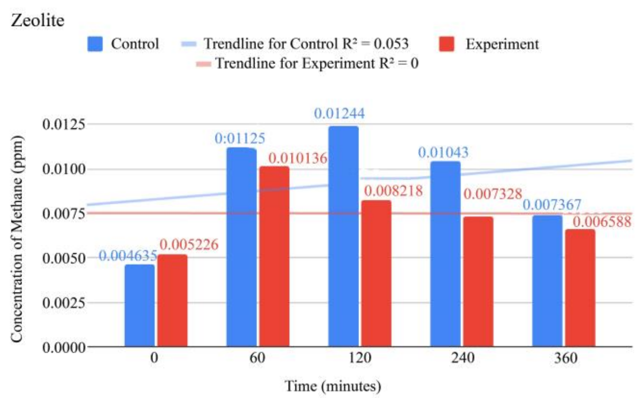

Fig. 4 Methane Emission Trends (0-360 mins) from Zeolite Overlaid Domestic Waste

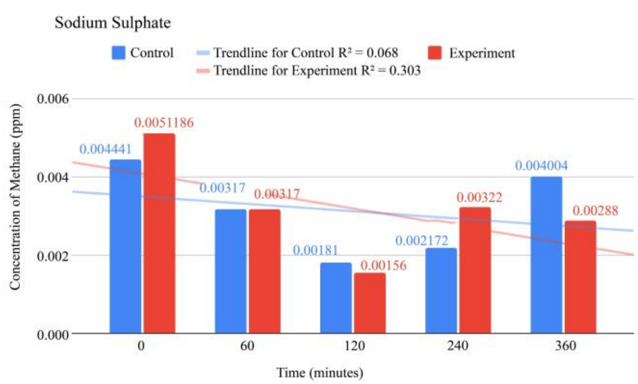

Fig. 5 Methane Emission Trends (0-360 mins) from 1 M Sodium Sulphate solution sprayed on Domestic Waste

From Table 1, it can be seen that the methane emissions in the experimental setup are generally lower than those in the control setup at some intervals. For example, at the 120-minute mark, the experimental setup had a methane emission of 0.00156 ppm, which is lower than the control setup's emission of 0.00181 ppm. Similarly, at the 360-minute interval, the experimental setup had an emission of 0.00288 ppm, while the control setup recorded a higher emission of 0.004004 ppm. However, at the 240-minute mark, the methane emission in the experimental setup increased to 0.00322 ppm, which is slightly higher than the control setup's emission of 0.002172 ppm. This variation indicates that, while there is a general trend of lower methane emissions in the experimental setup, there are instances where emissions fluctuate and exceed those of the control setup.

Usually Sodium Sulphate's reaction with Methane reduces Methane in a manner but also increases the amount of Sodium Sulphide, which, when reacted with moisture, produces Hydrogen Sulphide in the environment. Hydrogen Sulphide is a highly toxic gas, which is flammable and can be really harmful if not handled carefully [15]. It can also lead to fires in and around the waste collection site, putting the people around it at risk. This gas can also have adverse effects on people around the waste, as its chronic exposure leads to respiratory problems and neurological effects. This can be observed in the following reaction:

$$Na_2SO_4 + CH_4 \rightarrow Na_2S + H_2O + CO_2$$

$$Na_2S + H_2O \longrightarrow 2NaOH + H_2S$$

Sodium Sulphate can also dissociate themselves in the presence of water molecules into Sodium and Sulphate ions. Sulphate ions can react with water molecules to form Sulphuric acid molecules, which can lower the pH of the surrounding area. A decrease in pH can also reduce methanogenesis.

4. Conclusion

Methane, a potent greenhouse gas, is a major contributor to global warming and climate change, with landfill waste being a significant source of its emissions. This study assessed various interventions to reduce methane release from domestic waste. The compost-overlaid bin showed a slower rate of methane emission increase compared to the control bin, demonstrating moderate effectiveness, though less effective than some other methods. Conversely, the biochar-overlaid bin led to higher methane emissions, suggesting that biochar may worsen the issue and should not be used for such applications. Both zeolite and sodium sulfate solutions resulted in a substantial reduction in methane emissions; however, sodium sulfate's reaction with Methane indirectly produces hydrogen sulfide, a highly toxic and flammable gas that poses significant safety hazards. Of the interventions tested, zeolite emerged as the most effective in reducing methane emissions without producing harmful byproducts. To enhance the study's effectiveness and generalize the results, scaling up to larger, real-world settings such as landfill sites and garbage dumps is essential. Small sample sizes are prone to variations due to weather conditions, so future studies should be conducted under controlled environments to reduce errors. External factors like temperature, humidity, and sunlight may have influenced this field experiment, making it difficult to maintain control setups. Future research should focus on testing these interventions in real landfills, which could provide a global solution to methane emissions from waste. Exploring additional materials and varying their concentrations can help identify optimal solutions. Expanding the study with more replicates and waste types will make the results more generalizable. Customizing variables such as temperature, humidity, or waste volume while keeping others constant will aid in standardizing methane reduction techniques. By integrating technology and mathematical modeling, the study can be further refined, opening new possibilities for waste management and climate change mitigation.

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