Landfill gas mitigation using steel slag as a Biocover – A case study

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ABSTRACT

This study explores the potential of use steel slag as a biocover for dumpsite gas mitigation. Landfill sites are significant sources for greenhouse gases (GHGs), particularly methane (CH_4) and carbon dioxide (CO_2), which contribute to global warming and create environmental and health problems. This study explores the potential use of steel slag, an industrial byproduct, as an alternative bio cover material for LFG emission control and the study found that steel slag achieved a higher carbon dioxide reduction efficiency compared to soil covers. This research highlights the dual benefits of utilizing steel slag for gas control and promoting sustainable waste management by reuse of industrial byproducts. Based on the series of batch test slag showed sequester of 64.10mg/g carbon dioxide at moisture condition tested in 24hours. The primary objective of this study is to know the feasibility of using steel slag as a biocover material for mitigating gas emissions from landfills. This study aims to provide an alternative, cost-effective, and sustainable solution for landfill gas management while addressing the issue of industrial waste utilization, this work concludes that steel slag is a promising alternative biocover material for landfill gas mitigation.

Keywords: Environmental sustainability, industrial byproduct, methane emission reduction, sustainable materials.

1. INTRODUCTION

Dump sites are critical components of modern waste management systems and methane gas is the major sources of greenhouse gas (GHG) [1]. Methane, an effective GHG, has a global warming potential over 25 times greater than carbon dioxide (CO_2) over a 100-year period. Effective mitigation of landfill gas reduction is essential to reduce the environmental impact of waste disposal sites and contest climate change [2]. A conservative method for landfill gas management, such as burning and energy recovery systems, can be expensive and complex to implement. An alternative and innovative method is the use of biocovers to enhance microbi al oxidation of methane. Biocovers are layers of organic or inorganic materials applied to landfill surfaces to support the activity of bacteria, which convert methane into carbon dioxide and water [2]. This case study investigates the use of steel slag, a byproduct of steel manufacturing, as a biocover material for landfill gas mitigation. Steel slag is characterized by its high porosity, alkalinity, and abundance of nutrients, making it a promising candidate for enhancing methane oxidation processes. Utilizing steel slag not only addresses methane emissions but also contributes to the global economy by repurposing an industrial byproduct. At a municipal landfill site, where sections were covered with steel slag biocover. Methane emissions were monitored and compared with sections covered by conventional soil [4]. The objectives were to evaluate the effectiveness of steel slag in reducing methane emissions, assess its long-term stability, and determine its feasibility as a sustainable landfill gas mitigation strategy. This study gives the information about stage for understanding the potential benefits and challenges of using steel slag as a biocover material. The findings from this case study aim to provide insights into innovative and manageable approaches for landfill gas management, contributing to environmental protection and resource efficiency [3,4].

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1.1 Bio covers

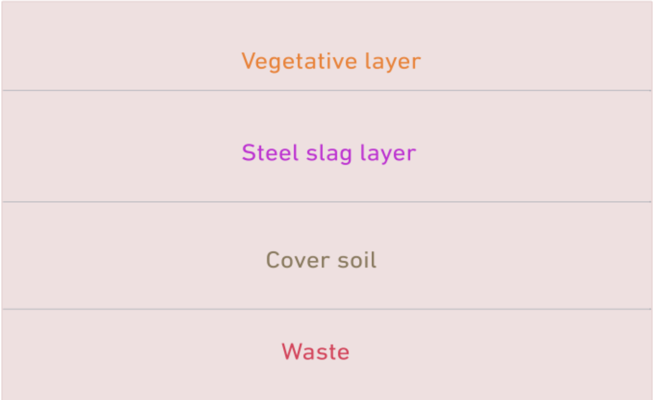

Figure 1: Biogeochemical cover system

Biocovers has an emerged as a promising technology for mitigating greenhouse gas emissions from landfills. MSW Landfills are significant sources of methane (CH_4), a strong greenhouse gas with a global warming potential far exceeding that of carbon dioxide (CO_2) figure 1 shows the biogeochemical cover system. Effective management of landfill methane emissions is essential for reducing the environmental impact of waste disposal and addressing about climate change [11]. Biocovers are engineered layers of organic or inorganic materials applied to the surface of landfills to improve the natural bacteriological oxidation of methane. The concept behind biocovers is to promote the progress and activity of bacteria, which break down methane into less harmful byproducts such as carbon dioxide and water. This biological process offers a sustainable and cost-effective alternative to traditional landfill gas management methods like flaring and energy recovery systems. Several materials have been studied for use as biocovers, including compost, soil, and industrial byproducts. The choice of biocover material is critical, as it must provide a suitable environment for methanotrophic bacteria, including adequate porosity, moisture content, and nutrient availability. Additionally, the material should be economically viable and readily available to ensure for common adoption [12].

One promising material for biocovers is steel slag, a byproduct of steel manufacturing. Steel slag is known for its high porosity, alkalinity, and nutrient content, which can create an optimal habitat for methanotrophic bacteria. Using steel slag not only improves the methane oxidation but also repurposes an industrial waste product, contributing to the principles of the country economy [12]. This study explores the quantification of steel slag as a biocover material for landfill gas mitigation. The study aims to assess the viability of steel slag biocovers in real-world conditions, evaluate their long-term stability, and determine their ecofriendly impact [13].

The scope of this study covers the experimental approach for investigating the behaviour of landfills with soil to innovate the biogeochemical cover under various environmental conditions. The study concentrates on low-cost biocover systems containing of steel slag in grouping with biochar to control the methane and carbon dioxide productions from landfills. Steel slag amended with soil protection cover considered and developed as an effective supportable Biocover [11].

Table 1: Composition of MSW in Bangalore

Waste type	Percentage (%)
Clothes	6.34
Plastics and papers	Plastics and papers 28 &12
Leather	0.8
Glass	1.28
Rubber	0.88
Metals	0.23
Stones	1.96

(Source: BBMP cell, 2022)

2. MATERIAL AND METODOLOGY

Test materials: Soil and Steel Slag are the materials used in this study.

2.1 **Soil:** Soil was collected from the Mittigenhalli waste yard site, placed in the village of Mittaganhalli in Bengaluru East Taluk, Bangalore Urban, and Karnataka, India. The samples were taken at a depth of 1 to 2 feet and transferred to the environmental Laboratory at the Department of Civil Engineering (UVCE), where the material was stored at room temperature of (25°C). The soil samples are air-dried, powdered, and passed through a 4.75 mm sieve before conducting all the experiments.

2.2 Steel Slag

The slags used in this research was attained from the iron and steel industry in Bengaluru. The slag is fine material and passing through 4.75mm sieve, slags was oven dried up at 105^0 C in order to all moisture content from the slag before conducting the experiments. The physical properties of the soil and steel slag are shown in below table 1 respectively.

2.3 METHODOLOGY

Batch Testing

For batch experiments glass vials of 100 ml with rubber closures were used. Calibration gas with known volume of methane and carbon dioxide was placed, place the tested materials in glass vials, which is soil, and slag (w/w) was placed into the bottle and wrapped with a rubber cock make sure there is no air leakage from the glass vials [12]. Allow gas contact with the materials in the glass vials with time. By using gas tight syringes gas samples were withdrawn from the bottle at every 0, 6, 12, and 24 hour's intervals. Collected gas samples were immediately analyzed by a Gas Chromatography (AGILENT) instrument with a gas flame ionized detector (FID) and a stainless-steel column with helium as a carrier gas, and the contentment's of methane and carbon dioxide were determined [12,13]. The following figure 2 shows flow chart for batch experiment.

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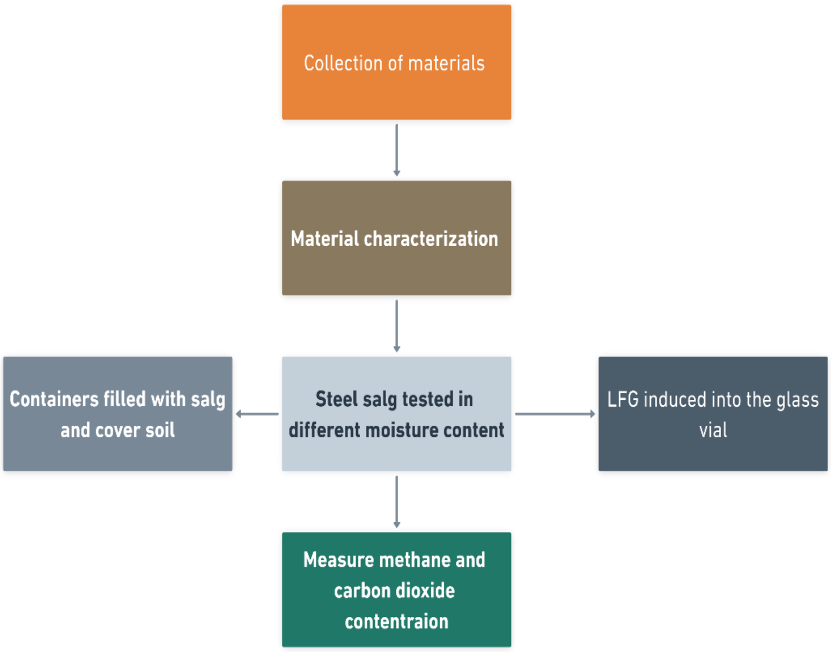

Figure 2: Flow chart for Batch Experiment

3 RESULTS AND DISCUSSION

The properties of soil and steel slag are presented in Table 1. The chemical properties of the steel slag and soil used in this research work are mentioned in Table 2. The specific gravities of the soil and slag are 2.59 and 1.3, respectively. The materials exhibited a range of pH levels, from slightly acidic at 5 for the soil to highly alkaline at 11 for the slag. The water holding capacity was 70.66% for the soil and 37.4% for the slag. The chemical and mineralogical composition of the soil and slag is detailed in Table 2.

Table 2: Properties of Soil, and steel slag

Properties	Soil	Slag
Specific gravity	2.59	1.3
Grain size distribution Gravel %	2.8	0.7
Sand%	13.1	16.4
Fines%	84.1	82.9
Coefficient of curvature Cc	1.2	1.0
Coefficient of uniformity Cu	1.1	2.9
Atterberg limits Liquid limit	34	Non-plastic
Plastic limit	20.1	Non-plastic
Water holding capacity	70.66%	37.4%
pH	5.04	11
Voids	52.01	46.4
Dry density	1.447 g/cm³	1.689g/cm³

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Table 3: Chemical and mineralogical composition of soil, slag

Oxides	Soil	Slag
Cao	0.14	1.17
Sio_2	55.06	2.09
Al_2o_3	32.96	2.90
Fe_2o_3	3.46	76.04
Mgo	1.02	17.36

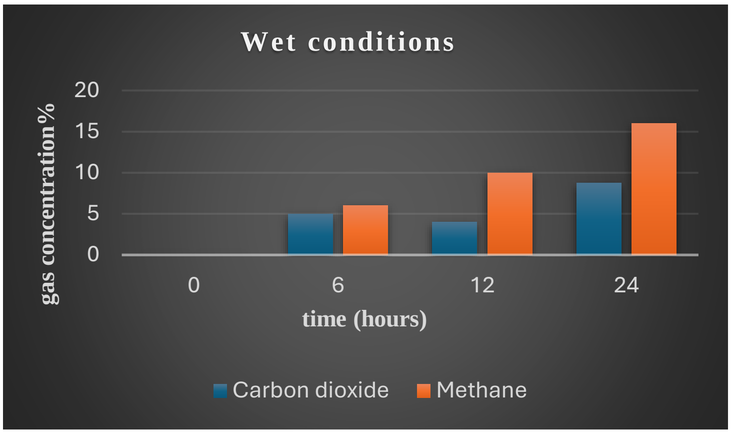

Figure 3: Methane & carbon dioxide uptake in wet soil condition

Fig 3 shows the results demonstrate that primary investigation done based on the series of batch experiments, methane generation is more in soil respect to time intervals and rapid under wet soil conditions. The intervals are like 0.6,12,24 hours Carbon dioxide showed a noticeable amount of generation in wet soil conditions. Y- Axis represents gas concentration and x-axis represents time in hours.

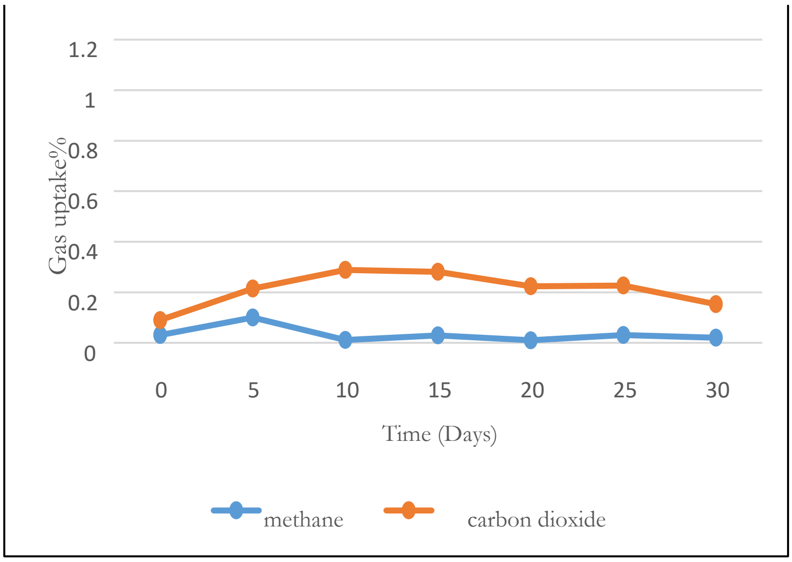

Figure 4: Methane and carbon dioxide uptake in soil

Figure 4 illustrates the plot of gas uptake over time in batch tests with cover soil. The increasing in methane uptake over a phase indicates methane oxidation by CH_4 -oxidizing bacteria present in the soil. This conclusion is supported by the lack of major changes in gas concentrations in the control tests (using sterilized soil and LFG), authorizing CH_4 oxidation by the naturally present CH_4 –oxidation by bacteria in the cover soil. Initially, a minimal CO_2removal of 29% by the soil was observed, followed by a rise in CO_2 levels due to the methane oxidation process. These findings suggest that the cover soil used in this study is rich in bacteria capable of oxidizing methane.

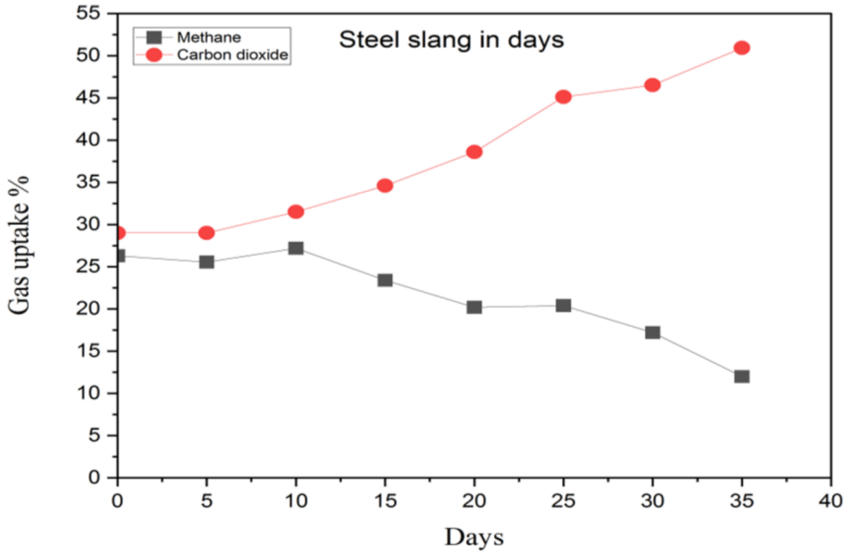

Figure 5: Methane and carbon dioxide uptake in Slag

Figure 5 depicts the gas uptake over several days in slag. The methane concentration shows a slight adsorption capacity by the slag, with 25.56% and 27.2% adsorption observed over 5 and 10 days, respectively. In contrast, there is significant removal of carbon dioxide, with 29% and 31.5% removed over the same periods. The maximum uptake of both CO_2 and CH_4 was observed over 35 days. Due to its high CaO content, the slag is highly reactive and effective for CO_2 sequestration. However, the highly alkaline nature of slag may negatively impact CH_4 oxidation when mixed with soil or biochar-amended soil. To investigate this, the slag is being tested in many groupings like soil alone and biochar-amended soil.

Figure 6 explains the CO_2 and CH_4 removal from the material observed during the batch experiments. These experiments highlighted the importance of moisture in slag and soil for the carbonation process under moist conditions. However, in 24 hours batch experiments, couldn't explain the direct relationship between carbonation process when presence of moisture. Among the various moisture contents established, the optimum moisture content for carbonation was found to be 30% from batch experiment. Which resulted in the maximum gas removal. Beyond this, lower carbon and methane removal rates were observed at 40% and 50% moisture content over time.

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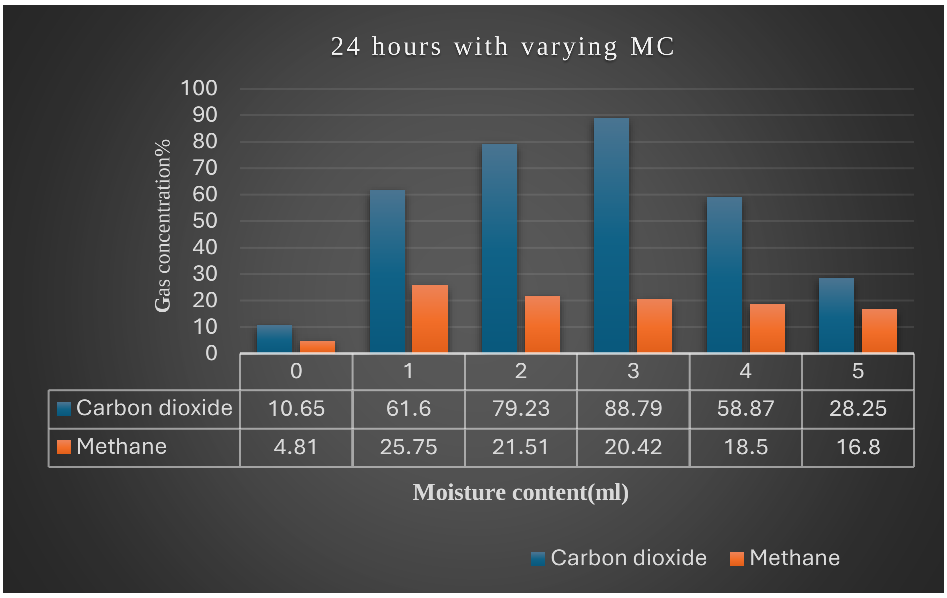

Figure 6: Gas uptake in 24hours with varying moisture content

The main purpose of this paper was to introduce the concept of biogeochemical cover which incorporates steel slag and soil in a cover system to mitigate emissions of CH_4 and CO_2, by facilitating CO_2 sequestration in steel slag [17]. The following discussion can be made from this study:

- The results of this study highlight the effectiveness of steel slag as a biocover material for mitigation of LFG. The application of steel slag demonstrated a significant reduction in methane compared to conventional soil covers [15,16].
- The different biogeochemical covers and soil control cover systems were used to treat LFG and it containing mixture of 50% CH_4, 50% CO_2 at an inflow rate of continuously 3minutes per day. steel slag possesses significant CO_2 sequestration capacity in individual as well as in mixed state (with soil) under moisture conditions [18]
- Overall, this study suggest that steel slag is a highly promising biocover material for landfill gas mitigation. it proves sustainability and cost effectiveness, make a strong landfill cover for large - scale landfill applications [19,20].

4 CONCLUSIONS

This study demonstrates that potential use of steel slag as an effective bio cover material for mitigating landfill gas emissions, particularly methane (CH_4). The results from laboratory trials indicate that sections of the landfill covered with steel slag bio covers showed a significant reduction in methane emissions compared to those covered with conventional soil. The properties of slag were determined and the results shows that slag is suitable for a biocover material to mitigate landfill gas emissions. Series of batch experiments slag showed capture of 64.102 mg/g of carbon dioxide at moisture conditions tested in 24 hours. A small amount of methane removal capacity was also identified by slag during the batch test at 24 hours (20.88mg/g) indicating it's possible to mitigate both CH_4 and CO_2 from landfill gas. From continuous batch tests, slag is shown to possess a high capacity for the sequestration of carbon dioxide gas in landfills. The particle size of the slag may have influenced its carbonation capacity. Steel slag bio covers offer a practical, cost-effective, and sustainable method for reducing greenhouse gas emissions from landfills. This innovative approach not only mitigates environmental impacts but also contributes to the valorisation of industrial waste, aligning with broader goals of sustainability and resource efficiency.

5. DECLARATIONS

5.1 GRANT DETAILS AND ACKNOWLEDGMENT

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5.2 CONFLICT OF INTERESTS

There is no conflict of interest regarding this research.

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