

Methanotrophic Methane Oxidation in New Biogeochemical Landfill Cover System

Raksha K. Rai

Department of Civil and Materials Engineering

University of Illinois at Chicago

842 West Taylor Street, Chicago, IL 60607, USA

rrai5@uic.edu

Krishna R. Reddy

Department of Civil and Materials Engineering

University of Illinois at Chicago

842 West Taylor Street, Chicago, IL 60607, USA

kreddy@uic.edu

Abstract: Municipal solid waste (MSW) landfills are regarded as one of the major sources of greenhouse gas (GHG) emissions across the world. In order to control these emissions, an innovative and sustainable biogeochemical cover system that consists of soil, biochar and basic oxygen furnace (BOF) slag is being developed to completely eliminate fugitive methane (CH_4) and carbon dioxide (CO_2) emissions from the landfills. The effectiveness of such cover systems is highly dependent on the survival and activity of methanotrophs under highly alkaline conditions induced by the presence of slag. In this study, a series of microcosm batch tests on landfill cover materials in different proportions were investigated to study the effect of cover materials on microbial CH_4 oxidation in the mixed as well isolated systems. Results demonstrated negligible CH_4 oxidation and substantial CO_2 sequestration when the BOF slag was integrated/mixed with soil (pH~7) and biochar-amended soil (pH~11). However, layered or separated cover material conditions (biochar-amended soil overlain by slag and soil overlain by slag) demonstrated promising CH_4 oxidation potential, thus concluding that extreme alkaline conditions inhibit the CH_4 oxidation. Overall, this study showed that a layered system consisting of the soil or biochar-amended soil layer overlain by BOF slag layer is optimal for CH_4 oxidation and subsequent CO_2 sequestration. Large column experiments and field test plots are being performed to evaluate the long-term performance of the proposed geochemical cover system under dynamic environmental (moisture and temperature) conditions.

Keywords: biogeochemical cover; BOF slag; biochar; methane oxidation; methanotrophs; carbon dioxide sequestration

INTRODUCTION

Landfills are the third largest source of anthropogenic CH₄ emissions in the United States. The landfill gas (LFG) typically comprises of 50% CH₄ and 50% CO₂, both of which are greenhouse gases impacting global climate change. Mitigation of CH₄ emissions has received greater attention for a long time, and many researchers evaluated reducing CH₄ emissions by studying the potential of CH₄ oxidizing bacteria present in the cover soil to convert CH₄ into CO₂ (Whalen et al. 1990; Kightley et al. 1995; Boeckx et al. 1996, Cao et al. 2011). In recent years, many researchers have focused on the use of biocovers that support microbial proliferation and enhance CH₄ oxidation. These biocovers typically employ organic-rich materials such as garden waste compost, yard waste, sewage sludge, peat, and biochar (Hummer and Lechner, 1999; Stern et al. 2007; Pedersen, 2011; Scheutz et al. 2011; Yargicoglu and Reddy, 2017) to enhance microbial CH₄ oxidation when placed alone or in amendments with soil.

In addition, an interest in utilizing industrial waste materials as components of landfill cover has also come into the limelight, due to their favorable physicochemical properties. Some of the industrial wastes that have shown potential landfill cover materials include paper mill sludge (Kovačić, 1996), coal fly ash (Nhan et al. 1996), bottom ash (Kim et al. 2016), and steel slag (Herrmann et al. 2010, Andreas et al. 2014) and they have been investigated as barrier or drainage layer depending on their hydraulic and geotechnical properties.

Steel slag, a byproduct from steel mills, has gained a significant attention in recent years, especially in the construction industry as an aggregate material and in environmental applications as media for contaminant adsorption and carbon dioxide sequestration. It is investigated in treating heavy metals from groundwater (Smith, 2003), phosphate removal from wastewater (Lu et al. 2008), heavy metals from acid mine drainage (Sheridan, 2014), and fertilizer/soil modifier in agriculture (Zhang et al. 2003; Kimio, 2015). Recently, Reddy et al. (2018) investigated use of BOF slag for sequestration of carbon dioxide from landfill gas emissions (Reddy et al. 2018).

An innovative, sustainable and practical biogeochemical cover system consisting of soil, biochar and BOF slag is being investigated to achieve zero emissions from the landfills (Reddy et al. 2018). The alkalinity and the presence of alkaline metals in BOF slag are conducive for CO₂ sequestration. However, it could be challenging for the microbial community in soil or biochar-amended soil to thrive under extreme alkaline condition induced by slag. The objective of this to investigate the effect of presence of these three landfill cover materials both on methanotrophic CH₄ oxidation and CO₂ sequestration.

BIOGEOCHEMICAL COVER CONCEPT

Biogeochemical cover is an innovative, low-cost landfill cover system consisting of steel slag in combination with soil and biochar (Reddy et al. 2018). Steel slag is a co-product of steel making process and basic oxygen furnace (BOF) slag is a type of steel slag, which is rich in alkaline minerals such as CaO, MgO, etc. The alkaline metal oxides present in the slag react with CO₂ forming stable carbonates. Many studies have explored the carbonation potential of steel slag for the mineral CO₂ sequestration. Past studies (Reddy et al. 2014; Yargicoglu and Reddy 2017) have shown promising potential in biochar-amended soil to mitigate CH₄ emissions by the enhanced methanotrophic oxidation of CH₄.

The biogeochemical cover aims to combine the carbonation potential of BOF slag with the methanotrophic CH_4 oxidation potential of biochar-amended soil to mitigate both the CH_4 and CO_2 emissions from the MSW landfills and ultimately leading to “Zero Emissions Landfill Cover”. **Figure 1** shows the schematic of the steel slag and biochar amended-soil biogeochemical cover system. The proposed biogeochemical cover also has the potential to sequester hydrogen sulfide (H_2S) if present in the LFG as shown in Figure 1. The use of proposed biogeochemical cover in landfills will not only reduce the environmental concerns associated with the fugitive LFG emissions but also opens up a door for the sustainable management of steel slags which are generally stockpiled in the steel industry or landfilled.

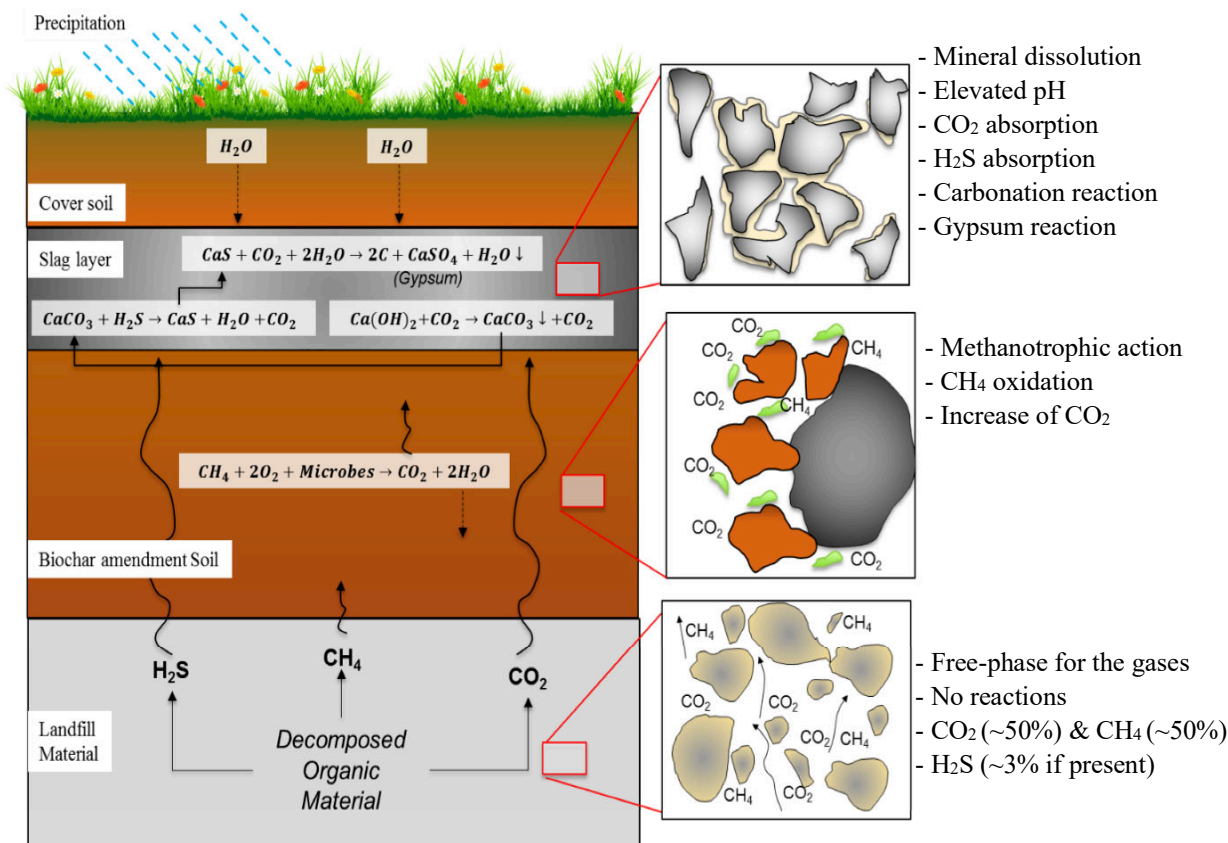


Figure 1: Schematic of biogeochemical cover system for zero emissions (Reddy et al. 2018)

Although the proposed biogeochemical cover offers wide range of environmental as well as economic benefits, it is of utmost importance to analyze various factors, which are crucial to the functioning of the coupled biogeochemical processes. A comprehensive laboratory testing program consisting of multiple tasks is undertaken for this purpose; this study presents the results from one of these tasks.

MATERIALS

Soil

Soil was collected from Zion landfill site, located in Greater Chicago area, Illinois, USA. Soil samples were collected from an interim cover layer at a depth of ~1 to 2 feet and were shipped to the Geotechnical and Geoenvironmental Engineering Laboratory at the University of Illinois at Chicago (UIC) where it was stored at room temperature ($23 \pm 2^\circ\text{C}$). Soil samples were air dried (moisture content $<0.5\%$), pulverized and screened through a 2 mm sieve prior to conducting the experiments.

Biochar (CE-WP2)

Biochar was obtained from a commercial vendor in Illinois, USA. The biochar used in this study was produced from pinewood pellets subjected to gasification at a high temperature of $\sim 520^\circ\text{C}$. In this study, biochar in pellet form was used- fines were sieved and discarded. The biochar was oven-dried at 105°C to remove any moisture content before conducting the experiments.

BOF Slag

The BOF slag used in this experiment was obtained from Indiana Harbor East of Arcelor Mittal steel industry, located in Indiana, USA. All the tests were performed using the slag as obtained from the plant. The steel slag was also oven-dried at 105°C prior to conducting the experiments.

METHODOLOGY

Properties Testing

The specific gravity of the three landfill cover materials was determined in accordance with the ASTM D854. ASTM D422 was followed to determine the grain size distribution of each material, while Atterberg limits of soil were determined as per ASTM D4318. Hydraulic conductivity was determined according to the ASTM D2434 (for biochar and slag) and ASTM 5084 for soil using a flexible wall triaxial set up. The water holding capacity (WHC) of all the materials were determined using procedure as described in Yargicoglu et al. (2015). Each material under investigation (10 g) was soaked in 0.01 M CaCl_2 solution (L/S of 1:1) for 2 hours prior to measuring pH, ORP and electrical conductivity as per ASTM D4972. The pH meter was calibrated with standard buffers of pH 4, 7 and 10 prior to testing. The organic content of the materials was analyzed following the ASTM D2974.

Batch Incubation Tests

Mixed Systems

10 g of the total material (soil, biochar, and BOF slag) individually and in different proportions (**Table 2**) was placed in 125 ml-serum vials and adjusted to a moisture content of 20% (w/w) using deionized water. The vials were sealed airtight using butyl rubber septa followed by crimp cap. 20 ml of air from the headspace of each vial was replaced with equal volume of synthetic LFG

comprising of 50% (v/v) CH₄ and 50% (v/v) CO₂ to achieve a headspace concentration of ~5-6% (v/v) CH₄ and ~5-6% (v/v) CO₂ balanced in air (~88-90%). The change in the headspace concentration was determined by collecting and analyzing the gas samples on a regular basis using gas chromatography (GC) until the headspace concentration dropped to less than 1%. All the experiments were conducted in duplicate/triplicate along with the controls (gas with no material). The controls using only soil (sterilized for 2 hours using Napco Model 8000-DSE autoclave) were also tested to discern any microbial activity in the soil. The CH₄ oxidation rates were calculated from the linear regression analysis of CH₄ concentration versus elapsed time, based on the zero-order kinetics.

Slag Isolated Systems

Separate series of incubation experiments were conducted in which soil and biochar-amended soil were not mixed with slag, but slag existed separated in a cage. A steel cage of size 2" x 2" x 2" was used to contain the steel slag (10% of the total material) and placed inside the serum vial using nylon thread to isolate slag from the soil and biochar-amended soil. The material was adjusted to the desired moisture content of 20%. The vial was sealed airtight using butyl rubber septa followed by crimp cap. Similar procedure as mixed system was followed in the isolated system to achieve the headspace concentration of ~5-6% (v/v) CH₄ and ~5-6% (v/v) CO₂ balanced in air (~88-90%).

Gas Analysis

The gas samples were analyzed at regular time intervals and analyzed for CH₄, CO₂ and O₂ concentrations using an SRI 9300 GC equipped with a thermal conductivity detector (TCD) and CTR-1 column that separates N₂ and O₂ for simultaneous analysis of CO₂, CH₄, O₂ and N₂. Gas samples were withdrawn using 1 ml syringe where 0.5 ml of the sample was discarded and remaining 0.5 ml was injected into the GC to reduce any pressure effects due to sampling. A calibration curve for a minimum of three points was established using high purity standard gas mixtures ranging from 1% to 50% CH₄ and CO₂.

RESULTS AND DISCUSSION

The physical and chemical properties of BOF slag, soil and biochar used in this study are summarized in **Table 1**. The BOF slag tested consisted of ~74% sand-sized particles and was classified as SP (poorly graded sand) according to Unified Soil Classification System (USCS). The specific gravity of the BOF slag, soil and biochar were determined as 3.4, 2.57 and 0.6, respectively. The hydraulic conductivity of BOF slag and biochar were both approximately 10⁻³ - 10⁻⁴ cm/s, consistent with typical values for fine sands to loose silt (Holtz and Kovacs 1981). The soil was highly impermeable with a hydraulic conductivity in the order of 10⁻⁸ cm/s. The WHC of soil, BOF slag, and biochar were 43%, 20% and 52% (w/w), respectively. BOF slag was observed to be highly alkaline with pH 12.4. The ORP of all three materials were negative, demonstrating higher reducing capacity.

Both mixed and slag isolated systems were investigated for pH at the beginning of the experiments. Soil, biochar and BOF slag had pH of 7.6, 6.7 and 12.4, respectively (**Table 2**). Many studies on landfill cover soil have shown pH ranging from 4.3 to 9 (Gebert et al. 2009; Chi et al. 2015) with most of them at near neutral pH. The biochar is reported to have a wide range of pH, highly dependent on the type of feedstock used. Yargicoglu et al. (2015) showed pH ranging from 6.24 to 8.86 for five different types of biochar, produced from coconut charcoal, pinewood, aged oak, pinewood pellets, and 90% pine with 10% fir wood. The BOF slag was highly alkaline in nature

due to the presence of basic oxides like CaO and MgO (Reddy et al. 2018; Bonenfant et al. 2008; Navarro et al. 2010). The amendment of BOF slag at 10% (total weight) in the mixed systems (slag-amended soil-biochar and slag-amended soil) decreased the pH by 1.4-1.5 units, keeping the overall pH at 10.9 and 11.03, respectively. This change in the pH was mainly due to high buffering capacity of the soil. However, the biochar-amended soil had the pH (7.4) close to the pH of the soil (7.6), indicating biochar had no major effect on the overall pH of the mixed materials.

Table 1: Physical and chemical characteristics of BOF slag, cover soil and biochar

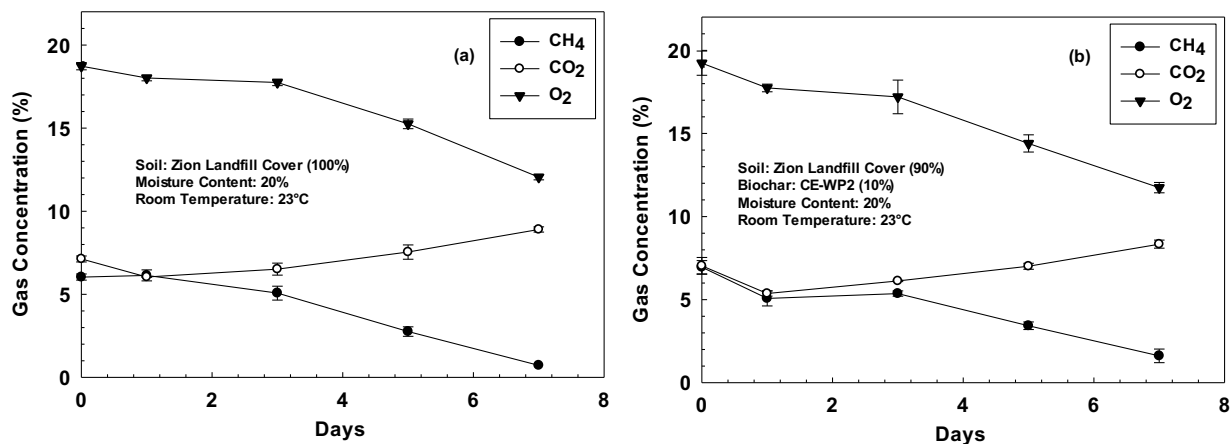
Properties	ASTM Method	BOF Slag	Soil	Biochar
Specific Gravity	D854	3.5	2.57	0.6
<i>Grain Size Distribution:</i>	D422			
Gravel (%)		20.8	3.7	45
Sand (%)		74.2	14.7	54
Fines (%)		4.9	81.9	1
D ₅₀ (mm)			0.009	4.3
C _c		0.7	-	0.82
C _u		18	-	2.42
<i>Atterberg Limits:</i>	D4318			
Liquid Limit (%)		Non-	39	Non-Plastic
Plastic Limit (%)		Plastic	22	
Plasticity Index (%)			17	
USCS Classification	D2487	SP-SM	CL	SP
Water Holding Capacity (w/w)		20	43	51.6
Dry Density (g/cm ³)		1.72	1.8	1.15
Hydraulic Conductivity (cm/s)	D2434	1.1 x 10 ⁻³	5.4 x 10 ⁻⁸	2 x 10 ⁻⁴
Loss of Ignition (%)	D2974	1.6	5.8	96.71
pH (1:1)	D4972	12.4	7.6	6.5
Electrical Conductivity (mS/cm)	D4972	13.3	0.55	0.8
Redox Potential (mV)	D4972	-313.3	-53.8	-6.3

C_c=Coefficient of curvature; C_u=Coefficient of uniformity

Table 2: pH of the mixed and slag isolated systems

Substrates	pH
Soil (100%)	7.6
Soil (90%) + Biochar (10%)	7.4
Soil (90%) + Slag (10%)	11.03
Soil (80%) + Biochar (10%) + Slag (10%)	10.90
Soil (90%) & Slag in Basket (10%)	7.6 (Soil); 12.4 (Slag)
Soil (80%) + Biochar (10%) & Slag in Basket (10%)	7.4 (Soil + Biochar); 12.4 (Slag)
Biochar (90%) & Slag in Basket (10%)	6.7; 12.4 (Slag)
Slag in Basket (100%)	12.4

Figures 2(a) and 2(b) show trends in CH₄ consumption, carbon dioxide production and oxygen consumption with time for soil and biochar-amended soil, respectively. An initial lag phase of 24-72 hours was observed, which could be mainly due to time needed for the adaptation of the microbial population to their environment. Thereafter, a gradual decrease in CH₄ concentration, increase in the CO₂ levels and decrease in the oxygen levels were observed, confirming CH₄ oxidation by the CH₄ oxidizing bacteria in both the systems. This was further confirmed using the controls (only sterilized soil and LFG) that showed no major change in the headspace gas concentration (not shown) confirming CH₄ oxidation by the naturally existing CH₄ oxidizing bacteria in the soil. The CH₄ oxidation rates calculated based on the zero-order kinetics were 89.2 µg/g/day and 79 µg/g/day, respectively, for soil and biochar-amended soil. The results from **Figure 2(b)** also suggests that the biochar had no major effect on the CH₄ oxidation process when amended with soil. Previous study from our research laboratory demonstrated promising results of biochar amendment in enhancing CH₄ oxidation rates in the long term, as the microbes take time for colonizing and acclimatizing (Yargicoglu and Reddy, 2017). The reason for negligible effect of biochar amendment in CH₄ oxidation in the current study could be attributed to the shorter duration of testing.

**Figure 2: Removal of methane with: (a) Soil and (b) Biochar-amended soil**

Figures 3(a) and 3(b) show changes in the gas concentrations with time for slag-amended soil and slag isolated soil. The slag-amended soil showed complete removal of CO₂ within the first few hours of the experiment, but showed negligible change in the CH₄ concentration throughout the course of experiment suggesting inhibition of CH₄ oxidation activity of the CH₄ oxidizing bacteria,

which could possibly be due to the high pH (11.03) of the system. However, in the slag isolated soil system, the slag was placed inside the steel mesh not in contact with the soil, wherein CH_4 oxidation by the soil and simultaneous CO_2 sequestration by the BOF slag was observed. The rate of CO_2 removal in the isolated system was slower when compared to the mixed system, which could likely be attributed to the diffusion limitations posed by the steel mesh. The CH_4 oxidation rates were $0.74 \mu\text{g/g/day}$ and $85.5 \mu\text{g/g/day}$, respectively, for slag-amended soil and slag isolated soil.

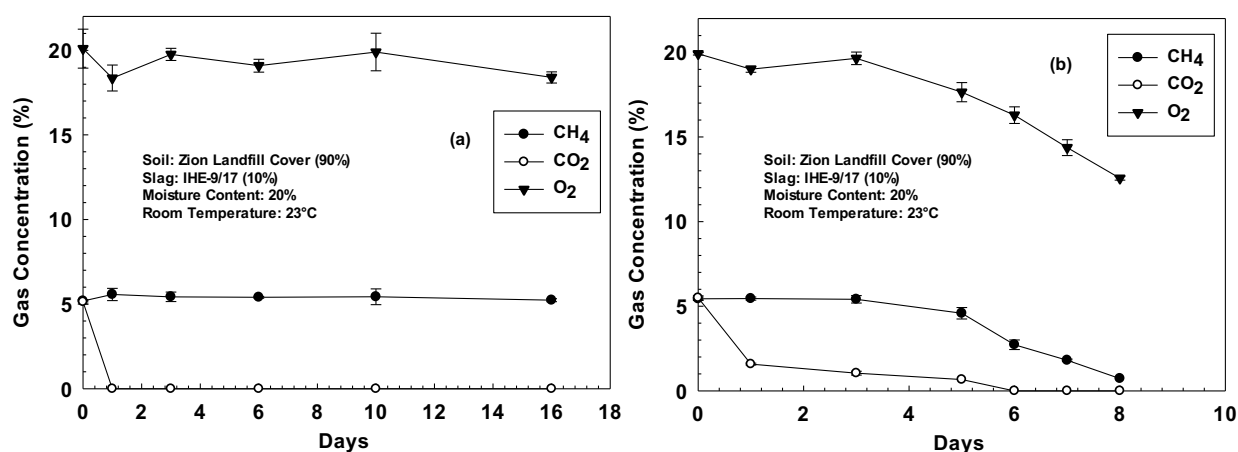


Figure 3: Removal of carbon dioxide and methane with: (a) Slag-amended soil (b) Slag isolated soil

Figures 4(a) and 4(b) show changes in the gas concentrations with time for slag-amended soil-biochar and slag isolated biochar-amended soil. No change in the CH_4 concentration was observed in the slag-amended soil-biochar similar to the slag-amended soil, but complete removal of CO_2 in the presence of BOF slag was noted. However, in the slag isolated biochar-amended soil, change in CH_4 concentration with time was observed showing CH_4 oxidation along with a prolonged removal of CO_2 . It is known that CH_4 oxidizing bacteria grow at a pH ranging from 5.5 to 8.5 in soils and sediments of different ecosystem (Dunfield 1993; Hutsch 1994; Scheutz and Kjeldsen 2004; Sherry et al. 2016; Han et al. 2016), although few methanotrophs growing in extreme environments such as soda lake and marine environments at pH 9-11 requiring NaCl for their growth (Kalyuzhnaya et al. 2008, Sorokin et al. 2000, Khmelenina et al. 1997) have been identified. Therefore, for an effective CH_4 oxidation to occur, slag isolated from the soil or overlain the soil is recommended so that methanotrophic activity is not inhibited by the high pH of the system. The CH_4 oxidation rate for these systems were calculated to be $0.98 \mu\text{g/g/day}$ (slag-amended soil-biochar) and $80 \mu\text{g/g/day}$ (slag isolated biochar-amended soil), respectively.

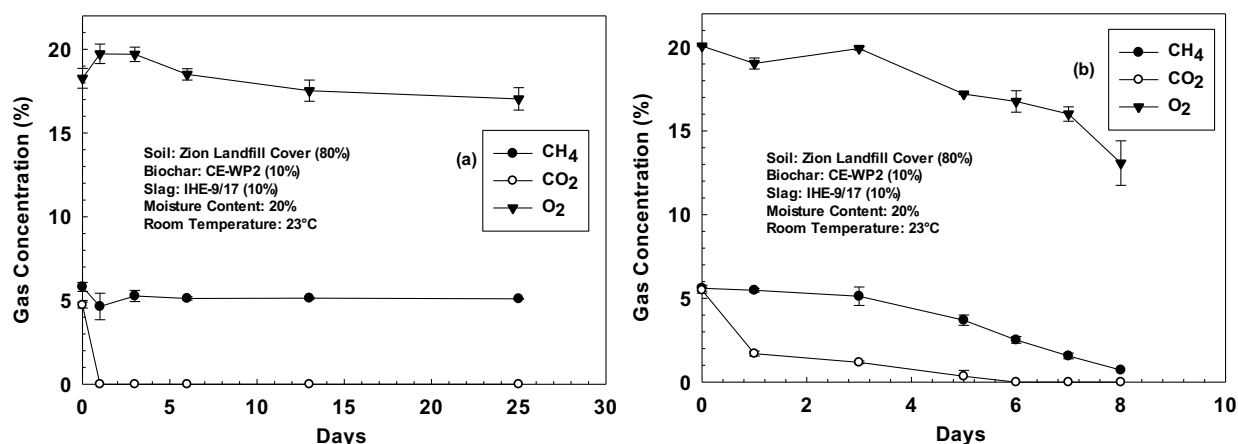


Figure 4: Removal of carbon dioxide and methane with: (a) Slag-amended soil-biochar (b) Slag isolated biochar-amended soil

Figure 5 shows trend in both CH₄ and CO₂ with time for BOF slag alone. The results show negligible removal of CH₄ and significant removal of CO₂ suggesting the BOF slag to be an invaluable material for CO₂ sequestration.

Overall, the three landfill cover materials studied demonstrated an effective CH₄ oxidation in the soil, slag isolated biochar-amended soil, slag isolated soil, and biochar-amended soil. It is important to note that negligible CH₄ oxidation in slag-amended soil-biochar and slag-amended soil was observed. Furthermore, BOF slag demonstrated significant potential in sequestering CO₂ in both mixed as well as slag isolated systems.

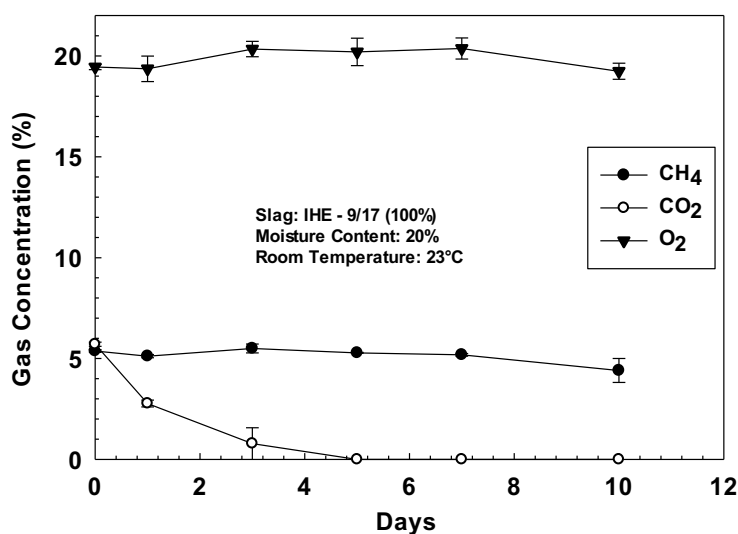


Figure 5: Removal of carbon dioxide using BOF Slag

CONCLUSIONS

Laboratory investigation on the landfill cover materials was conducted to study the effect of cover materials (soil, biochar-amended soil, and BOF slag) on the CH₄ oxidation and CO₂ sequestration. Our results demonstrated that the landfill cover soil was dominated by the CH₄ oxidizing bacteria and were responsible for the CH₄ oxidation. No negative impact on the CH₄ oxidation was observed when the soil was amended with biochar, but a negative effect was observed when the BOF slag was mixed with soil or biochar-amended soil. Nevertheless, BOF slag showed effective CO₂ sequestration in both mixed and slag isolated systems. Therefore, our results propose the use of slag-isolated soil or slag isolated biochar-amended soil systems for an effective CH₄ oxidation and simultaneous CO₂ sequestration in the biogeochemical landfill cover system. Column tests and field-scale evaluation of slag isolated biochar-amended soil cover systems are being performed in order to better understand the effect of BOF slag on microbial CH₄ oxidation under the long-term field environmental conditions.

ACKNOWLEDGEMENT

This research is a part of comprehensive project titled “Innovative Biochar-Slag-Soil Cover System for Zero Emissions at Landfills” funded by the National Science Foundation (CMMI# 1724773). The authors are thankful to Dennis Grubb, Girish Kumar, Jyoti Chetri, and Archana Gopakumar for their assistance during this study.

REFERENCES

- Andreas, L., Diener, S., and Lagerkvist, A. (2014). “Steel slags in a landfill top cover—Experiences from a full-scale experiment”. *Waste Management*, 34(3), 692-701.
- Boeckx, P., Van Cleemput, O., and Villaralvo, I. D. A. (1996). “Methane emission from a landfill and the methane oxidizing capacity of its covering soil”. *Soil Biology and Biochemistry*, 28(10-11), 1397-1405.
- Bonenfant, D., Kharoune, L., Sauve, S., Hausler, R., Niquette, P., Mimeault, M., and Kharoune, M. (2008). “CO₂ sequestration potential of steel slags at ambient pressure and temperature”. *Industrial & Engineering Chemistry Research*, 47(20), 7610-7616.
- Cao, Y., and Staszewska, E. (2011). “Methane emission mitigation from landfill by microbial oxidation in landfill cover”. *International Conference on Environmental and Agriculture Engineering IPCBEE*, 15, 57.
- Chi, Z. F., Lu, W. J., and Wang, H. T. (2015). “Spatial patterns of methane oxidation and methanotrophic diversity in landfill cover soils of Southern China”. *J. Microbiol. Biotechnol.*, 25(4), 423-430.
- Dunfield, P., Dumont, R., and Moore, T. R. (1993). “Methane production and consumption in temperate and subarctic peat soils: response to temperature and pH”. *Soil Biology and Biochemistry*, 25(3), 321-326.
- Gebert, J., Singh, B. K., Pan, Y., and Bodrossy, L. (2009). “Activity and structure of methanotrophic communities in landfill cover soils”. *Environmental Microbiology Reports*, 1(5), 414-423.
- Han, J. S., Mahanty, B., Yoon, S. U., and Kim, C. G. (2016). “Activity of a methanotrophic consortium isolated from landfill cover soil: Response to temperature, pH, CO₂, and porous adsorbent”. *Geomicrobiology Journal*, 33(10), 878-885.

- Herrmann, I., Andreas, L., Diener, S., and Lind, L. (2010). "Steel slag used in landfill cover liners: laboratory and field tests". *Waste Management & Research*, 28(12), 1114-1121.
- Holtz, R. D., and Kovacs, W. D. (1981). "An Introduction to Geotechnical Engineering". Prentice Hall, New Jersey.
- Kalyuzhnaya, M. G., Khmelenina, V., Eshinimaev, B., Sorokin, D., Fuse, H., Lidstrom, M., and Trotsenko, Y. (2008). "Classification of halo (alkali)philic and halo (alkali) tolerant methanotrophs provisionally assigned to the genera *Methylobacterium* and *Methylobacter* and emended description of the genus *Methylobacterium*". *International Journal of Systematic and Evolutionary Microbiology*, 58(3), 591-596.
- Khmelenina, V.N., Kalyuzhnaya, M.G., Starostina, N.G., Suzina, N.E., and Trotsenko, Y.A. (1997). "Isolation and characterization of halotolerant alkaliphilic methanotrophic bacteria from Tuva soda lakes". *Microbiology*, 35, 257-261.
- Kightley, D., Nedwell, D. B., and Cooper, M. (1995). "Capacity for methane oxidation in landfill cover soils measured in laboratory-scale soil microcosms". *Applied and Environmental Microbiology*, 61(2), 592-601.
- Kim, G. W., Ho, A., Kim, P. J., and Kim, S. Y. (2016). "Stimulation of methane oxidation potential and effects on vegetation growth by bottom ash addition in a landfill final evapotranspiration cover". *Waste Management*, 55, 306-312.
- Kimio, I. T. O. (2015). "Steelmaking slag for fertilizer usage." Nippon Steel Sumitomo Metal Tech Rep, 109, 130-136.
- Kovacic, D. (1996). "Materials for the final cover of sanitary landfills". *International Journal of Rock Mechanics and Mining Sciences and Geomechanics Abstracts*, 1(33), 40A.
- Lu, S. G., Bai, S.Q., and Shan, H. D. (2008). "Mechanisms of phosphate removal from aqueous solution by blast furnace slag and steel furnace slag." *J. Zhejiang Univ. Sci.* 1066 A, 9(1), 125-132.
- Navarro, C., Díaz, M., and Villa-García, M. A. (2010). "Physico-chemical characterization of steel slag. Study of its behavior under simulated environmental conditions". *Environmental Science & Technology*, 44(14), 5383-5388.
- Nhan, C. T., Graydon, J. W., and Kirk, D. W. (1996). "Utilizing coal fly ash as a landfill barrier material". *Waste Management*, 16(7), 587-595.
- Pedersen, G. B., Scheutz, C., and Kjeldsen, P. (2011). "Availability and properties of materials for the Fakse Landfill biocover". *Waste Management*, 31(5), 884-894.
- Reddy, K. R., Yargicoglu, E. N., Yue, D., and Yaghoubi, P. (2014). "Enhanced microbial methane oxidation in landfill cover soil amended with biochar." *Journal of Geotechnical and Geoenvironmental Engineering*, 140(9), 04014047.
- Reddy, K.R. and Grubb, D.G. and Kumar, G. (2018). "Innovative biogeochemical soil cover to mitigate landfill gas emissions," Proceedings of the *International Conference on Protection and Restoration of the Environment XIV*, Thessaloniki, Greece.
- Scheutz, C., and Kjeldsen, P. (2004). "Environmental factors influencing attenuation of methane and hydrochlorofluorocarbons in landfill cover soils". *Journal of Environmental Quality*, 33(1), 72-79.
- Scheutz, C., Fredenslund, A. M., Chanton, J., Pedersen, G. B., and Kjeldsen, P. (2011). "Mitigation of methane emission from Fakse landfill using a biowindow system". *Waste Management*, 31(5), 1018-1028.
- Sheridan, C. (2014). "Remediation of acid mine drainage using metallurgical slags." *Miner. Eng.*, 64, 15-22.

- Sherry, A., Osborne, K. A., Sidgwick, F. R., Gray, N. D., and Talbot, H. M. (2016). "A temperate river estuary is a sink for methanotrophs adapted to extremes of pH, temperature and salinity". *Environmental Microbiology Reports*, 8(1), 122-131.
- Smith, J. S. (2003). "Method for purifying contaminated groundwater using steel slag". U.S.1117 Patent No. 6,602,421.
- Sorokin, D. Y., Jones, B. E., and Kuenen, J. G. (2000). "An obligate methylotrophic, methane-oxidizing *Methylobacterium* species from a highly alkaline environment". *Extremophiles*, 4(3), 145-155.
- Stern, J. C., Chanton, J., Abichou, T., Powelson, D., Yuan, L., Escoriza, S., and Bogner, J. (2007). "Use of a biologically active cover to reduce landfill methane emissions and enhance methane oxidation". *Waste Management*, 27(9), 1248-1258.
- Su, T. H., Yang, H. J., Shau, Y. H., Takazawa, E., and Lee, Y. C. (2016). "CO₂ sequestration utilizing basic-oxygen furnace slag: Controlling factors, reaction mechanisms and V–Cr concerns". *Journal of Environmental Sciences*, 41, 99-111.
- Whalen, S. C., Reeburgh, W. S., and Sandbeck, K. A. (1990). "Rapid methane oxidation in a landfill cover soil". *Applied and Environmental Microbiology*, 56(11), 3405-3411.
- Xie, T., Sadasivam, B. Y., Reddy, K. R., Wang, C., and Spokas, K. (2015). "Review of the effects of biochar amendment on soil properties and carbon sequestration". *Journal of Hazardous, Toxic, and Radioactive Waste*, 20(1), 04015013.
- Yargicoglu, E. N., Sadasivam, B. Y., Reddy, K. R., and Spokas, K. (2015). "Physical and chemical characterization of waste wood derived biochars". *Waste Management*, 36, 256-268.
- Yargicoglu, E. N., and Reddy, K. R. (2017). "Biochar-amended soil cover for microbial methane oxidation: Effect of biochar amendment ratio and cover profile". *Journal of Geotechnical and Geoenvironmental Engineering*, 144(3), 04017123.
- Zhang, Y. L., Liu, M. D., Wang, Y. J., and Du, L. D. (2003). "Effects of slag application on Si, Fe and Mn in paddy soil and rice plant." *Chinese J. Soil Sci.*, 4, 016.



The 34rd International Conference on Solid Waste Technology and Management

March 31- April 3, 2019
Annapolis, MD • U.S.A.

The Journal of Solid Waste Technology and Management
Department of Civil Engineering | Widener University
1 University Place Chester, PA 19013-5792 USA
Phone: 610-499-4018 | Fax: 610-499-4461
Email: icsw@solid-waste.org • solid-waste.org

ISSN 1091-8043

© 2019 Journal of Solid Waste Technology and Management
The responsibility for contents rests upon the authors and not upon
JSWTM or Widener University

OPENING PLENARY

<u>Sustainable Waste Management in Ribboning and Retting Process of Jute – an alternative to Plastics, Sadhan Kumar Ghosh, India</u>	1
--	---

SESSION 1A

Landfill 1

<u>Status of Solid Waste Landfill in Benin Metropolis, Nigeria, Dennis Iyeke Igbinomwanhia, Ohikhokhai Gift Aizebeoje, Osaghale Andrew Ehizogie, Nigeria</u>	10
--	----

SESSION 1B

Waste Generation and Composition

<u>Comparative Study of Solid Waste Characteristics and Management Practices in Two Towns of Punjab Province of Pakistan, Khalid Iqbal, Madeeha Rafi, Tayyaba Noreen, Pakistan</u>	14
--	----

<u>Grain-Class-Specific Water Contents of Different Waste Streams, Kay Johnen, Alexander Feil, Germany</u>	26
--	----

<u>Generation and Characterization of Solid Waste in a Peri-Urban Community in Sub-Saharan Africa, Olubunmi Mokuolu, Medinat Abdulsalam, Nigeria</u>	33
--	----

<u>Solid Waste Generation and Management in Schools Within Samaru Kaduna State Nigeria, Fatima Badiru Ibrahim, Khadijat Abdulkareem Abdulraheem, Ahmed M. Baba, Nigeria</u>	40
---	----

SESSION 1C

Use of Wastes in Construction 1

<u>Structural Performance of Concrete Elements Constructed Using Recycled Concrete Aggregate and Recycled Tyre Steel Fibres, Hynda Aoun-Klalib, Nicholas Barnes, Bahareh Kaveh, UK</u>	51
--	----

<u>Durability Performance of Flat Panel Display Glass Concrete, Grady Mathews IV, Robert Bylone Jr., Harry Nash, Dr. Shirley Clark, USA</u>	61
---	----

<u>Utilization of Industrial By-Products in Self-Compacting Concrete, Nikita Gupta, Rafat Siddique, India</u>	71
---	----

SESSION 1D

Public Education and Involvement

<u>Household Solid Waste Management in Monrovia, Liberia: Influencing factors, Characteristics, and Management Solutions, Victor Emer David Jr, China</u>	80
---	----

<u>Attitudes and Behaviour of Residents towards the Management and Recycling of Municipal Solid Wastes in Olievenhoutbosch, South Africa, Ndivhewafhi Oscar Makhale Isaac Tebogo Rampedi, South Africa</u>	91
--	----

SESSION 2A

Policy and Regulations

<u>Governance Failure in Public Service Delivery: A Study of Solid Waste Management in Kathmandu Metropolitan City, Nepal, Indra Prasad Dahal, Nepal</u>	103
--	-----

<u>An Assessment of Policy Related to Municipal Solid Waste Management in Botswana, Daniel Mmereki, Kgosiésele Velepini, Larona Mosime-Serero, Vietnam</u>	117
--	-----

<u>Development of Municipal Solid Waste Policy in Lebanon, Mervat El-Hoz, Lebanon</u>	130
---	-----

SESSION 2B

Construction and Demolition Wastes

<u>Recovery of External Thermal Insulation Composite Systems Containing EPS as Part of a Circular Economy, Martin Simons, Alexander Feil, Germany</u>	142
---	-----

<u>The Reuse of Waste in the Brazilian Construction Industry, Marienne do Rocio de Mello Maron da Costa, Luiz Felipe Cordeiro, Michael Isaac Gabriel Santos, Marisa, Soares, Borges, Brazil</u>	150
---	-----

<u>Estimation of construction waste with rectangular prism and pyramidal shape method in urban areas of Pakistan, J. Rafi, M. Rafi, M. Mushtaq, Qatar</u>	162
---	-----

SESSION 2C

Geotechnical Use of Wastes

<u>Dry Density-Water Content Curves for High Plasticity Clays Treated with Fly Ash, Stone Dust and Combinations, Darga Kumar Nandyala, India</u>	173
--	-----

<u>Experimental Research on a New Solid Waste Stabilizer KC of Stabilizing Chloride Soil, Yin Cheng, Jing Chen, Ya-fei Li, Luo Dai-song, China</u>	185
--	-----

<u>Experimental Investigations Using Waste Materials in the Stabilization of Expansive Soils, Kandru Suresh, Musini Venkateshwarlu, KSV Praveena, India</u>	194
---	-----

<u>Characteristics of Apparent Electrical Resistivity on Compacted Clays Mixed with Lime and Fly Ash, Fang Li, Shulin Sun, deheng zhang, P.R. China</u>	206
---	-----

SESSION 2D
Biological Treatment

Application of Mixed Organic Waste for Effective Septage Treatment through In-vessel Co-composting, *Anu Rachel Thomas, Martin Kranert, Ligy Philip, NIL, India* 217

Biodegradable Waste management techniques for Apartments complexes and Gated communities for Metro cities- Best Practices of Bruhat Bengaluru Mahanagarapalike(ULB of Bengaluru City), *jyothilakshmi Ramaswamy, Sumangala Patil, India* 227

Impact of Seasonal and Regional Influences on the Quality of Separately Collected Biological Waste, *Melanie Brune, Christoph Jansen, Alexander Feil, Germany* 233

SESSION 2E
Energy Recovery

Trial Calculation to Obtain the Upper Price Limit for a Complete Electricity Generation System Based on Waste Incineration, *Masafumi Tateda, Ryoko Sekifuji, Japan* 239

Challenging Situation to Optimise 100% Pet Coke With 15% Tsr: A Case Study at Ambujanagar, *Bibekananda Mohapatra, Pravesh Kumar Sharma, Ramsinh Chauhan, Mr. Atul Kumar Chaturvedi, Ms. Reshu Chauhan, Mr. Sukuru Ramarao, India* 246

SESSION 3A
Agricultural Wastes

Assessment of Environmental Impact and Nutrient Content of Oil Palm Slurry in Livestock Nutrition in Nigeria, *Adejoke Adeneye Mako, Oluwanike Abiola-Olagunju, Victor Olusegun Akinwande, Nigeria* 258

Novel Application of Ultrasonic Pretreatment of Giant Reed Co-Digested with Chicken Manure for Biogas Recovery, *Zainab Ismail, Nazik Noori, Iraq* 263

Reverse Logistics of Agrochemical Packaging in Brazil: Case Study, *Ariane Braga Oliveira, Bruno Fernando Gianelli, Sandro Donnini Mancini, Brazil* 274

Characteristics of Wood Pellets Mixed with Torrefied Rice Straw, *Kazuei Ishii, Toru Furuichi, Ryosuke Kizuka, Masahiro Sato, Satoru Ochiai, Japan* 282

SESSION 3B
Ash

Study on the Use of Post Processed MSWI Ash in Concrete and Mortar, *Grady Mathews IV, Reem Alsinan, Michael Young, USA* 292

SESSION 3D
Case Studies

Some Aspects of Household Food Waste Generation and Treatments Options: A Case Study of Mamelodi and Montana in the City of Tshwane Metropolitan Municipality in South Africa, **301**
Morwesi Silvia Ramotse, Isaac Tebogo Rampedi, South Africa

The Practices and Challenges for Municipal Solid Waste Management in Temeke Municipality, Dar Es Salam, Tanzani, **315**
Ahmed Lubwama, Tanzania

SESSION 3E
Environmental Assessment 1

The Impact of the Maintenance Phase in a Life Cycle Assessment of Houses, **330**
Enedir Ghisi, Andrea Invidiata, Brazil

Piecewise Nonlinear Regression: A statistical Method for the Analysis of Experimental Adsorption Data by the Intraparticle-Diffusion Models, **340**
Mohammad Elkhaiary, Egypt

Single-Use Plastics: How Prepared Are Ireland and the US for Sustainability? **348**
Anita Zavodska, Anne Morrissey, USA

SESSION 4A
Landfill 2

Methanotrophic Methane Oxidation in New Biogeochemical Landfill Cover System, **360**
Raksha Rai, Krishna Reddy, USA

Evaluation of Unsaturated Hydraulic Behavior of Evapotranspiration (ET) Cover through Field Instrumentation and Numerical Modeling, **372**
Md Jobair Bin Alam, Prabesh Bhandari, Farnaz Seraj, USA

SESSION 4B
Use of Wastes in Construction 2

Portland Composite Cement: An Sustainable Product in Indian Scenario, **384**
Bibekananda Mohapatra, Pravesh Kumar Sharma, Ambuja Cements Ltd., Varsha Liju, Sanjeev Chaturvedi, India

Performance of Concrete with Recycled Plastic Waste for Flood Defence Barrier Systems, **402**
Bahareh Kaveh, Hynda Aoun-Klalib, Tom Kemp, UK

SESSION 4C
Electronic Wastes

E-Wastes Management in Nigeria: Challenges and Prospects, **412**
Fatima Badiru Ibrahim, Abubakar Ismail, Nigeria

SESSION 4D
Plastics Wastes

Plastic Waste Management and Public Health Concerns in Bangladesh, *Mohammad Habibur Rahman, Alauddin Ahmed*, ITN-Buet, **Bangladesh** 422

A Sustainable Approach for Post-Consumer PET Bottles Recovery and Reduction in Nigeria, *Olaide Monsor Aderaju, Antonio Guerner Dias, Peter C Ekweozoh, Iquo Offiong*, **Portugal** 429

SESSION 4E
Contaminated Sites 1

Upward Electrokinetic Remediation (UEKR) for Contaminated Sediments with Heavy Metals, *Arulpoomalai A, Shashidhar T*, **India** 441

POSTER SESSION 1

Alternatives for Red Mud Reuse in Civil Engineering Construction Materials after Environmental Accidents in Brazil, *Liseane Padilha Thives, João Francisco Thives da Luz Fontes, Mayara S.S. Lima*, **Brazil** 448

SESSION 5C
Policy, Economics and Management

Smart City Development: A Step towards Solid Waste Management and Sustainable Development, *Anaya Ghosh, Sadhan Kumar Ghosh*, **India** 461

How the Commodities Recovery and the Restoration/Disaster Industries Can Work Closer Together for Expanded Business Opportunities, *Stephen Baruch, Jason Teliszczak*, **USA** 470

A Situational Analysis of Municipal Solid Waste Management Practices in Sara-i-Alamgir City, Pakistan, *Khalid Iqbal, Muhammad Ali*, **Pakistan** 480

SESSION 5D
Tire/Rubber Wastes

Utilization of Scrap Tires and Waste Oil as Supplementary Fuels in Cement Production, *Gizem Eker, Vedat Pinarli*, **Turkey** 493

After 10 Years Implementation of the Environmental Legislation about Scrap Tires Disposal, What Has Changed in Brazil, *Liseane Padilha Thives, Enedir Ghisi, Gabriela Hammes, Yuri Mello Muller de Oliveira*, **Brazil** 499

SESSION 6A

Environmental Assessment 2

A Pilot Study on EIA Report Quality in the Management and Recycling of Proposed Hazardous Waste Management Projects in The Gauteng Province of South Africa, *Willem Abraham Foord Ceronio, Isaac Tebogo Rampedi, South Africa* 510

Drinking and Domestic water Use Near an Open Dumpsite in a Peri-urban Community, *Olubunmi Mokuolu, Ifeoluwa Olaniyi, Nigeria* 523

Dispersion of Heavy Metals from Tshikondeni Exxaro Coal Dump, Limpopo Province, South Africa, *Phumudzo Gift Munyai, Jason Samuel Ogola, Lufuno Reginald Kone, South Africa* 529

SESSION 6B

Biochemical Treatment

A Viable Mechanical-Biological Waste Treatment Technology, *Glen Tobiason, Germany* 539

SESSION 6D

Special Wastes

Safe Removal and Disposal Procedures of Asbestos Containing Waste In Italy, *Sergio Bellagamba, Federica Paglietti, Sergio Malinconico, Beatrice Conestabile Della Staffa, Ivano Lonigro, Paolo De Simone, Italy* 551

Economic Potential of Gold Mine Waste: A Case Study of Consolidated Murchison Mine Waste, *Rembuluwani Solly Ravele, Jason Ogola, Humbulani Rejune Mundalamo, South Africa* 562

Impact of Asbestos Waste on Receiving Streams, *Bolaji Sule, Olayemi Olanlokun, Gbemi Olanlokun, Nigeria* 574

SESSION 6E

Sludge

Mineralogical characterization of sewage sludge for use as raw material in civil construction, *Maria Ingunza, Luis Yermán, David Williams, Brazil* 583

POSTER SESSION 2

Evaluation of Physical and Mechanical Parameters of Construction and Demolition Waste for Geotechnical Applications, *Jéssica Menezes, Erinaldo Cavalcante, Guilherme Bravo Almeida, Brazil* 590

Effect of Pressure on the Surfactant Pretreatment of Wastewater Sludge to Maximize the Drainability, *Mohsen Taghavijeloudar, Junboun Park, South Korea* 602

<u>Effects of Fly Ash Addition on the Rheological Behaviour of Red Mud Slurry, Maria P.D. Ingunza, David Williams, Sebastian Q. Olaya, Brazil</u>	610
--	------------

SESSION 7A *Case Studies 2*

<u>Consulting Support and Automatization as the Basic for the Eco-Industrial Park's Development in Russia, Dmitry Yaroslavtsev, Alexander Liubarskaia, Russia</u>	617
--	------------

<u>Tracking the Movement of Waste and its Environmental Impact: An Institutional Case Study, Patrick Caton, Howard Ernst, Karen Flack, Prof. Joseph Smith, Prof. Kurtis Swope, USA</u>	625
---	------------

SESSION 7C *Use of Wastes in Construction 3*

<u>Gold Mine Tailings as a Construction Material: A Case Study of the Klein Letaba Gold Tailings Dam, Limpopo Province, South Africa, Ndivhuwo Nemapate, South Africa</u>	637
--	------------