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Characteristics of Biochar-Amended Soil Cover for Landfill Gas Mitigation

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ABSTRACT

In this study, biochar-amended soil cover was investigated to enhance reduction of CH₄ emissions from landfills. This paper presents physical and chemical characteristics of biochar-amended soils. Specifically, moisture content, organic content, ash content, pH, particle size distribution, Atterberg limits, specific gravity, and permeability tests were conducted with biochar alone, soil alone, and biochar-amended soils. Moreover, batch experiments were performed using biochar alone, soil alone, and biochar-amended soils to quantify the effects of biochar amendment on adsorption of CH₄. The batch testing showed that the maximum methane adsorbed in biochar-amended soil was higher than that for soil alone, due to the adsorption of CH₄ to biochar, providing favorable conditions for methanotrophic oxidation to improve CH₄ degradation within the cover.

1 INTRODUCTION

Methane (CH₄) is becoming a priority because its global warming effect is 21 times more powerful than carbon dioxide (CO₂). Landfill gas generated from municipal solid waste (MSW) mainly consists of CH₄ and CO₂. It is reported that landfills are the second largest anthropogenic source of CH₄ emissions in the United States (USEPA, 2006). In many natural systems and within soils, methane oxidation occurs without any human interference and is considered to be an important sink for natural methane emissions (Humer and Lechner 1999). However, they are not sufficient to remove most of CH₄ generated within landfills. Only 15% of the generated CH₄ was removed from conventional landfill cover system (Park et al., 2010). In order to enhance the oxidation process, investigations on specific amendment to landfill cover have been carried out. Most of the previous studies focused on utilization of biomass after certain biodegradation process such as compost, which could provide better environment for microorganisms when it is amended into the conventional landfill cover soil than that alone. However, those materials cannot address adverse impacts of moisture content on methane oxidation in detail. With unique physico-chemical characteristics, biochar has the potential to improve the transport of gases through landfill cover even when the moisture content is relatively high.

Biochar is the carbon-rich product obtained when plant based biomass is heated in closed container with little or no available oxygen. The process is very close to production of charcoal, but biochar is intended to be applied to soil as soil amendment. Biochar improves soil productivity, carbon (C) storage, and soil ability to hold onto nutrients (Lehmann and Joseph, 2009). The physical and chemical characteristics of biochar contribute to the way in which they affect soil systems. Each soil has its own distinct physical properties depending upon its mineral and organic matter, and the way in which organic matter is associated (Brady and Weil, 2008). By adding biochar to a system, its contribution to the physical nature

of the system is significant. It will influence depth, texture, structure, porosity, and consistency by changing the surface area, pore-size distribution, particle-size distribution, and density. Biochar possesses high surface area, being higher than clay, will cause a net increase in the total soil-specific surface when amended to soil (Lehmann and Joseph, 2009). Because of its high surface area and porosity, biochar has been linked to improve soil structure or soil aeration in fine-textured soils (Kolb, 2007).

Microbial activities within soil are strongly influenced by moisture, temperature, and pH (Wardle, 1998). Soil bacterial community was largely explained by soil pH, with highest bacterial activity being in neutral soils and lowest in acidic soils (Fierer and Jackson, 2006). One of the important properties of biochar is its very high affinity and capacity for sorbing organic compounds. This non-linear sorption behavior of biochar often describes as adsorption to external or internal surfaces (Lehmann and Joseph, 2009).

This paper presents physical and chemical characterization of a biochar and its amendment to soil. The adsorption of CH₄ by biochar and biochar-amended soil is also investigated. These results helped to assess the potential for using biochar and biochar-amended soil to control CH₄ emissions at landfills.

2 RESEARCH METHODOLOGY

2.1 Materials

Cover soil was a silty clay soil obtained from the Carlinville Landfill in Carlinville, Illinois. Prior to use for testing, soil was autoclaved at 121°C for 30 min for two consecutive days (Benett et al., 2003). Soils were sealed at 22 °C for 24 hours between autoclave treatments (Carter et al., 2007). Biochar tested for this research was produced by Chip Energy Inc, (Springfield, Illinois) from a gasification process (520 °C) of wood pellets. Biochar was received from the supplier in a sealed drum. For the

laboratory experiments, biochar was transferred from the drum to a storage container.

2.2 Physical and Chemical Characterization Testing

The significance of the effect of biochar amendment on the properties of soil mixture was investigated. The physical and chemical characteristics of soil, including the organic content, pH, and permeability will change due to the amendment. That effect then will have a direct impact on the landfill gas mitigation behavior because the diffusion and advection of methane, availability of oxygen and water, environment for microbial activities within the landfill cover is determined largely by the physical and chemical properties of soil. In this study, the physical and chemical characteristics of the biochar and biochar amended soils were determined. The biochar percentage of 5 and 20 % (w/w) per weight of soil are tested. Specifically, moisture content, organic content, pH, particle size distribution, Atterberg limits, specific gravity and permeability of biochar, control soil, and biochar amended soils were tested.

2.2.1 Moisture Content

Moisture content of soil, biochar and soil amended with biochar was determined in accordance with ASTM D2216. Moisture content of biochar was conducted in accordance with ASTM D1762, the standard test method for chemical analysis of wood charcoal.

2.2.2 Organic Content

The organic content of soil, biochar, and soil amended with 5 and 20% biochar was determined in accordance with ASTM D2974. The organic content of biochar was determined in accordance with ASTM D1762.

2.2.3 Ash Content

Ash content of biochar was determined in accordance with ASTM D1762.

2.2.4 pH

The pH of soil, biochar, and soil amended with 5 and 20% biochar was measured in accordance with ASTM D4972. The pH of biochar (sieved through No. 10 sieve) was conducted with ratio of 1:10 biochar and distilled de-ionized water respectively (McLaughlin, 2010).

2.2.5 Specific Gravity

Specific gravity of soil, biochar, and soil amended with biochar was obtained in accordance with ASTM D854.

2.2.6 Particle Size Distribution

Particle size analysis of soil, biochar and soil amended with 5 and 20% biochar per weight of soil was conducted in accordance with ASTM D422. The percentages of different grain sizes contained within the material were determined by performing sieve and hydrometer analysis.

The mechanical or sieve analysis was performed to determine the distribution of the coarser, and larger sized particles, and hydrometer method was used to determine the distribution of the finer particles (<0.075 mm). A particle-size distribution curve was used to determine the C_u , C_c , D_{60} , D_{30} , and D_{10} parameters (Das, 2002).

2.2.7 Atterberg Limits

Atterberg limits were determined for soil, biochar and biochar amended soil after passing through sieve No. 40 in accordance with ASTM D4318.

2.2.8 Hydraulic Conductivity

Hydraulic conductivity or permeability tests were performed on biochar in accordance with ASTM D2434. To calculate hydraulic conductivity, Darcy's law was used. Hydraulic conductivity of soil and soil amended with 5 and 20% biochar (w/w) per weight of soil was measured by flexible wall triaxial method in accordance with ASTM D5084.

2.3 Batch Adsorption Testing

Glass bottles of 250 ml with long sleeve rubber stoppers were used for batch tests. Simulated landfill gas with identical percentages for methane and carbon dioxide of 25% complemented by nitrogen was used. Approximately 10-15 g of the material to be tested, which is soil, biochar, or biochar amended soil with 5 and 20% of biochar (w/w) of soil with the biochar size as received from the processing plant (retained on sieve #4) was placed into the bottle in a sealed tube, before the synthetic landfill gas is injected into the bottle. The time was set as soon as the cap of the tube was removed and the gas began to have contact with the material. Gas samples were taken from the bottle using syringes approximately every 15 sec after the cap is removed from the tube and the cover material gets contact with the gas. Then the gas samples were immediately analyzed by a Gas Chromatograph (SRI 9300B) equipped with a gas thermal conductivity detector (TCD) and a stainless steel column with helium as a carrier gas, and the concentrations of methane and carbon dioxide were determined.

3 RESULTS AND ANALYSIS

3.1 Physical and Chemical Characteristics

3.1.1 Moisture, Organic, and Ash Content

Table 1 shows the values for moisture, organic, and ash content of soil, biochar, and soil amended with 5 and 20% biochar per weight of soil. This study shows that amendment of biochar to soil increases its moisture content which is highly related to its high porosity and water holding capacity. Water is a universal biological solvent thus its presence in biochar pores increases the habitability of biochar to microbial activities substantially (Lehmann and Joseph, 2009). Amending high organic matter content biochar to soil increases its water holding capacity and therefore increasing its microbial culture

density and activity. Ash content of biochar in this study was 7.3% and biochar was made from hardwood feedstock which has been linked to have low ash content (Raveendran et al., 1995).

Table 1. Water, Organic, and Ash Content of Soil, Biochar and Soil amended with Biochar

Property	Soil	Biochar	Soil+5% Biochar	Soil+20% Biochar
Water content (%)	2.82	4.50	3.52	3.80
Organic content (%)	3.10	32.0	7.25	19.0
Ash content (%)	—	7.30	—	—

3.1.2 pH

The pH of soil, biochar and soil amended with 5 and 20% biochar were 5.3, 8.7, 6.6, and 7.3, respectively. The results of pH testing show an increase in pH value when 20% of biochar (w/w) added to soil from acidic condition of 5.3 to neutral state of 7.3. The diversity and richness of soil bacterial communities differ largely by soil pH, with higher bacterial diversity and activity in neutral soils and lowest in acidic soils (Wardle, 1998). Based on this study, amending biochar to landfill cover soil increases its pH and make the landfill cover a more suitable environment for methanotrophic bacteria to grow and multiply.

3.1.3 Specific Gravity

Specific gravity of soil, biochar and soil amended with 5 and 20% biochar were 2.6, 0.81, 2.1 and 1.8, respectively. The reason for lower specific gravity of soil amended with biochar is that the soil particles are replaced by organic biochar particles which weigh less than soil particles.

3.1.4 Particle Size Distribution

Fig. 1 compares the particle size distribution curves of soil, biochar, 5 and 20% (w/w) biochar amended soil together. Soil had particle size distribution of 0% gravel, 8.3% sand, 58.6% silt, and 33% clay with D_{60} and D_{30} parameters of 0.2 mm and 0.003 mm, respectively. Biochar had particle size distribution of 67.8% gravel, 31.4% sand, 0.8% silt, and 0% clay with D_{60} , D_{30} , D_{10} , C_u , and C_c parameters of 0.15 mm, 0.035 mm, 0.01 mm, 12.5, and 0.68, respectively. Soil amended with 5% of biochar (w/w) had the particle size distribution of 3.45% gravel, 10.7% sand, 51.4% silt, and 34.5% clay with D_{60} value of 0.02 mm. Adding 20% of biochar to the landfill cover soil had the particle size distribution of 7.25% gravel, 14.2% sand, 50% silt, and 28.5% clay with D_{60} and D_{30} values of 0.03 mm and 0.018 mm, respectively. The particle size distribution, D_{60} , and D_{30} values of biochar changes with its feedstock. Amending biochar to landfill cover soil increased the particle sizes, and biochar particle size increases porosity of the soil and promotes

the air flow through the landfill cover. Thus, more O_2 diffusion within landfill cover will result, leading to potentially higher microbial oxidation/degradation of CH_4 .

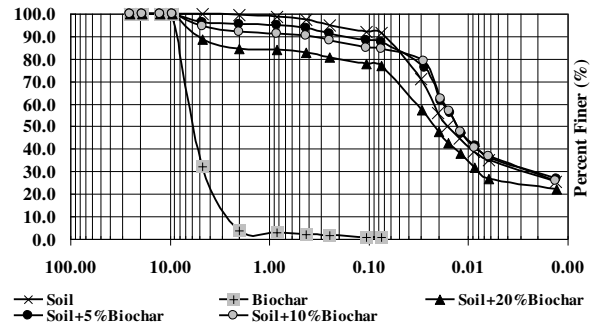


Figure 1. Grain size distribution of soil, biochar and biochar-amended soils

3.1.5 Atterberg Limits

The liquid limits, plastic limit, and plasticity index of soil were 31%, 19%, and 12% respectively. Conducting the Atterberg limit testing on biochar showed that biochar is non-plastic. The liquid limit, plastic limit and plasticity index of 20% biochar per weight of soil was 39%, 27%, and 12%, respectively. Amending 5% of biochar (w/w) of soil had a liquid limit, plastic limit, and plasticity index of 35%, 21%, and 14%, respectively.

3.1.6 Hydraulic Conductivity

Hydraulic conductivity tests (using rigid-wall permeameter) conducted on biochar resulted hydraulic conductivity of 1.2×10^{-3} cm/s. Hydraulic conductivity testing on soil using the flexible wall triaxial method resulted in hydraulic conductivity of 4.3×10^{-9} cm/s. Adding 5 and 20% of biochar (w/w) to soil increased its hydraulic conductivity from 4.3×10^{-9} cm/s to 5.72×10^{-9} and 3.5×10^{-8} cm/s, respectively. Higher permeability of soil due to amending biochar will result in higher gas diffusion within the landfill cover soil which in turn increases the O_2 diffusion and CH_4 transport within the cover. Ultimately, more O_2 availability will enlarge the oxidation layer of landfill cover by increasing the microbial activities and culture density resulting in higher oxidation efficiency within the cover.

3.2 Effect of Biochar on Adsorption of CH_4

Fig. 2 shows the comparison of maximum methane adsorption potential calculated from the results of batch testing conducted on landfill cover soil alone, biochar alone, and landfill cover soil amended with 5 and 20% (w/w) biochar (shown as 95S5B and 80S20B, respectively, in the figure). The maximum methane adsorbed increases from an average of 54 mL/kg for soil only to 77 mL/kg when 5% biochar (w/w) is added and to 156 mL/kg when 20% biochar (w/w) is added. Biochar alone has a high adsorption potential of 580 mL/kg.

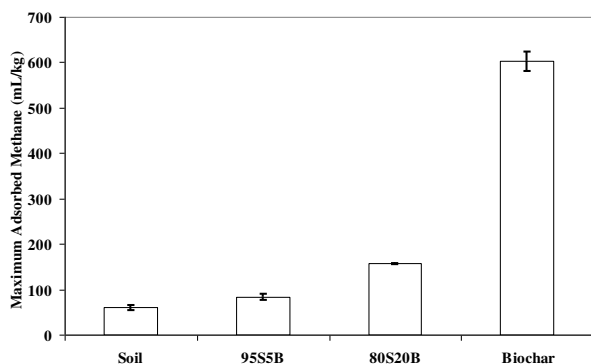


Figure 2. CH₄ adsorption to soil, biochar and biochar-amended soils (95S5B: 95%Soil+5%Biochar; 80S20B: 80%Soil+20%Biochar)

4 CONCLUSIONS

In this study, characteristics of biochar-amended soil cover were investigated to enhance reduction of CH₄ emissions from landfills. Physical and chemical characteristics of soil, biochar and biochar-amended soils, particularly moisture content, organic content, ash content, pH, particle size distribution, Atterberg limits, specific gravity, and permeability were determined. Amending biochar to landfill cover soil improved its physical and chemical characteristics to favor enhanced adsorptive capability and moreover habitability for microorganisms to grow and multiply in order for methane oxidation activities.

Batch testing showed that biochar increased soil's adsorptive capability for CH₄ removal. However, the saturation potential of biochar amended landfill cover with methane which will result in no reduction in methane emission should be considered. Therefore, an interaction between adsorption and microbial oxidation of methane within biochar amended landfill cover soil for an optimal solution to reduction of CH₄ emission to the atmosphere is being investigated.

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