Waste Management xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

Evaluation and statistical optimization of methane oxidation using rice husk amended dumpsite soil as biocover

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ARTICLE INFO

Article history:
Received 18 March 2015
Revised 16 September 2015
Accepted 17 September 2015
Available online xxxx

Keywords:
CH_4 oxidation
PBD
Landfills
Biocover
BBD
Rice husk

ABSTRACT

A laboratory scale study was conducted to investigate the effect of rice husk amended biocover to mitigate the CH_4 emission from landfills. Various physico-chemical and environmental variables like proportion of amended biocover material (rice husk), temperature, moisture content, CH_4 concentration, CO_2 concentration, O_2 concentration and incubation time were considered in the study which affect the CH_4 bio-oxidation. For the present study, sequential statistical approach with Placket Burman Design (PBD) was used to identify significant variables, having influential role on CH_4 bio-oxidation, from all variables. Further, interactive effect of four selected variables including rice husk proportion, temperature, CH_4 concentration and incubation time was studied with Box–Behnken Design (BBD) adopting Response Surface Methodology (RSM) to optimize the conditions for CH_4 oxidation. In this study, the maximum CH_4 oxidation potential of 76.83 $\mu gCH_4\ g_{dw}^{-1}\ h^{-1}$ was observed under optimum conditions with rice husk amendment of 6% (w/w), 5 h incubation time at 40 °C temperature with 40% (v/v) initial CH_4 concentration. The results for CH_4 oxidation potential also advocated the suitability of rice husk amendment in biocover system to curb emitted CH_4 from landfills/open dumpsite over conventional clay or sand cover on supplying CH_4 and O_2 to microbes on maintaining proper aeration.

1. Introduction

Methane (CH_4) emissions from landfills can be controlled up to a larger extent by promoting the rate of oxidation in aerobic soil cover on top of the landfill. Landfill cover soil acts as a transition zone between the dumped waste and the atmosphere, where overall higher mitigation efficiency can be achieved easily by microbial-mediated oxidation process at active or closed waste dumpsites. Anaerobic decomposition of organic waste dumped in landfills produce a large quantity of biogas comprises of approximately 64% CH_4, 35% CO_2 and <1% volatile odorous compounds (De Visscher et al., 1999). Landfills are known to be one of the most important sources of anthropogenic CH_4 emission (IPCC, 2007) accounting for 10–70 Tg (teragram) per year and around 11% of the total anthropogenic CH_4 produced per year. With increase in recognition of climate change, many developed countries have focused their policies towards stabilization of landfill gas through regulated implementation of landfill gas recovery or diminished disposal of organic or biodegradable waste in dumpsites or landfill sites. But in contrast much has to be done in developing countries. Even IPCC 4th assessment report 2007 has also projected that landfill CH_4 emission may reach up to 820–1000 Mt CO_2eq by the year 2020 in developing countries, under the burden of population explosion, per capita waste increase and change in landfill waste disposal technology (Bogner et al., 2007). The difference between global atmospheric sources and sinks of CH_4 is less than 6% of the total CH_4 production. Therefore, even a small reduction in anthropogenic CH_4 emissions would be significant to mitigate the problem which can be managed through proper management practices at landfill sites (Stern et al., 2007). Collection and utilization of landfill gas for energy purpose is an effective way to control the CH_4 emission from landfill. However, implementation of collection system is not economically feasible at older sites and also not worth for small dumpsites with fugitive emission. At some of such sites landfill gas (LFG) is either flared or just allowed to emit in the atmosphere, but in both of the senses it cause environmental pollution. Recently, research has also focused on development of low-cost technologies to mitigate the landfill CH_4 emission from the

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http://dx.doi.org/10.1016/j.wasman.2015.09.023
0956-053X/

waste dumping sites. IPCC has also recommended enhanced landfill CH_4 recovery and optimization of methanotrophic CH_4 oxidation and biofilters as potential measure to control landfill gas emission from waste sector. CH_4 from landfills can be mitigated without causing undue pressure on society. Establishment of biocover systems to facilitate bio-oxidation of CH_4 on making use of aerobic methanotrophs, which is one of such technologies to control CH_4 emission on oxidation of CH_4 to CO_2 and biomass. Furthermore, it is well documented that a high rate of CH_4 oxidation can be achieved through sustained microbial CH_4 oxidation or its enhancement in biofilters or engineered biocovers (Chanton and Liptay, 2000; Stern et al., 2007; Abichou et al., 2009). Currently, USEPA and IPCC set the default value at 10% emitted CH_4 for landfill cover CH_4 oxidation, which is quite low (IPCC, 2006). Indeed, several field studies have shown an oxidation rate of around 50% for a landfill cover soil (Whalen et al., 1990; Chanton et al., 2011).

CH_4 oxidation depends upon many factors like pH, moisture, temperature, and type of bed material used for the biocover to optimize the environment for methanotrophic bacteria. Conventionally relative low-permeable clay barrier is widely used to minimize infiltration of landfill gas to environment. However, it was confirmed from the recent studies that bio-oxidation of CH_4 can be enhanced on using different compositions of landfill cover material (Scheutz et al., 2011). The biocover should not only be sufficiently permeable for oxygen transport but also have good moisture holding capacity (Stern et al., 2007). The selection of suitable material is one of the key issue for constructing biocover for bio-oxidation of released CH_4 from landfills. Moreover, unsuitable material under unfavorable conditions may lead to production of CH_4 rather than its oxidation (Barlaz et al., 2004; Scheutz et al., 2009). However, to construct a CH_4 oxidation system at broad level, huge amount of suitable substrates are needed. The availability and cost associated with the substrate compel current research to focus on use of waste products, by products and residues, including sewage sludge (Börjesson et al., 1998), composts (Humer and Lechner, 1999; Barlaz et al., 2004; Mor et al., 2006; Stern et al., 2007; Abichou et al., 2009), compost mixtures (Jugnia et al., 2008) or even mechanically and biologically treated waste (Einola et al., 2007). But still, rice husk (RH) was unexplored as an alternate material for biocover construction. RH is a bulky waste material and readily available as a by-product of the rice milling process. In view of these characteristics, for the present study performance of biocover developed on mixing RH with dumpsite soil was investigated.

Bio-oxidation of CH_4 can be enhanced on optimizing the substrate concentration and process parameters/factors. Conventional batch mode optimization method, involved single parameter optimization at one time, taking other factors as constant. Such methods are not only time consuming but also lacks information on interactive effects of parameters on CH_4 oxidation. While statistical designs used in present study, allow identification of significant factors for bio-oxidation of CH_4 and their true optimization on explaining interaction between them. Until now, there have been no previous report, explaining the interactive effect of CH_4 concentration, rice husk amended biocover material, temperature and incubation time on bio-oxidation of CH_4 using RH amendment in biocover. In the present study, an attempt was made at lab scale level on using rice husk, a waste agro-industrial residues, as an alternate amendment material in mixture with dumpsite soil for the remedy of the problem of CH_4 emission from landfills. In this work, sequential statistical designs, Plackett–Burman Design (PBD) and Box–Behnken Design (BBD), were applied to establish the optimum conditions of initial CH_4 concentration, moisture content, temperature, and incubation time for bio-oxidation of CH_4 using rice husk as amendment in biocover design.

2. Materials and methods

2.1. Open dumpsite soil and rice husk characterization

Open dumpsite soil exposed to bio-methane, generated from anaerobic decomposition of organic matter, was collected from surface (0–10 cm) and subsurface profile (10–30 cm) of an existing dumpsite located at Hisar, Haryana (India) using shovel and hand trowels. All the soil samples were stored at collected moisture state in dark condition at 4 °C. In the laboratory, the soil sample was segregated, air dried, ground, sieved to 2 mm and mixed to ensure homogeneity prior to pre-incubation. A mixture of surface and subsurface soil was used in the present study.

RH sample used in the present study was procured from local rice sheller plant. The substrate was air dried, ground to 2 mm size and stored at room temperature in air tight container until further use.

The physical and chemical characteristics of soil samples and rice husk used in the study were done using standard methods. Moisture content of the soil samples was determined gravimetrically by drying at 105 °C for 24 h. The pH was measured from soil–water suspension (1:5 w/v) using pH meter. Cellulose, hemicellulose and lignin contents in rice husk sample was estimated by gravimetric method (Goering and Van Soest, 1970). Organic carbon content in both the dumpsite soil and rice husk was determined by dry combustion method (Nelson and Sommers, 1982). Standard Micro Kjeldhal method (Bremner and Mulvaney, 1982) was used for the estimation of total nitrogen in both of the samples and ash content in rice husk was determined by method of Han and Rowell (1997). Heavy metals content in both of the samples were analyzed on Flame Atomic Absorption Spectrophotometer (Shimazdu AA 6300) using wet digestion method. The physico-chemical characteristics of both the samples used for the study are presented in Table 1.

2.2. Experimental design

Response surface methodology (RSM) is an approach that combines various statistical and mathematical techniques, and is useful for developing, improving and optimizing a process. In the present study, sequential statistical designs, Plackett–Burman Design (PBD) and Box–Behnken Design (BBD), were used for identification and optimization of various factors affecting the bio-oxidation of CH_4 using amendment of rice husk in dumpsite soil to develop a biocover which can efficiently manipulate CH_4 emission from dumpsite. Step wise statistical modeling for optimization of various parameters to enhance the CH_4 oxidation capability of

Table 1
Physico-chemical characterization of the open dumpsite soil and rice husk samples.

Parameters	Dumpsite soil	Rice husk
pH	8.3	–
Moisture content	37.8	–
Cellulose contents	–	35
Lignin	–	15.2
Total organic carbon	24.6	26.2
Total nitrogen	1.34	0.51
Ash	–	20
Fe	4.49	0.02
Cr	0.62	BDL[a]
Mn	0.74	0.006
Cd	0.62	BDL[a]
Ni	0.078	BDL[a]
Pb	0.14	BDL[a]
Zn	0.37	0.001

The units are in % of dry weight except in pH and heavy metals (mg/kg).
[a] BDL: Below Detection Limit.

Please cite this article in press as: Bajar, S., et al. Evaluation and statistical optimization of methane oxidation using rice husk amended dumpsite soil as biocover. Waste Management (2015), http://dx.doi.org/10.1016/j.wasman.2015.09.023