Available online at www.sciencedirect.com
ScienceDirect
Chemosphere 67 (2007) 1582–1587
CHEMOSPHERE
www.elsevier.com/locate/chemosphere

Assessment of MSWI bottom ash organic carbon behavior: A biophysicochemical approach

Eva Rendek, Gaëlle Ducom *, Patrick Germain

Laboratoire d'Analyse Environnementale des Procédés et des Systèmes Industriels LAEPSI, INSA-Lyon, 20 avenue Albert Einstein, F-69621 Villeurbanne, France

Received 12 July 2006; received in revised form 27 November 2006; accepted 28 November 2006
Available online 17 January 2007

Abstract

In order to understand the influence of organic components on the behavior of municipal solid waste incinerator bottom ash, samples from five French incinerators have been analyzed and compared. Biological and physico-chemical experiments were coupled with a view to developing a new rapid assessment method of bottom ash quality. Bottom ash had different total organic carbon contents ranging from 8.8 g kg^{-1} to 37.4 g kg^{-1}. A part of this organic carbon can be leached into the environment or provide a substrate for microbial activity. Samples showed really different behaviors regarding these processes. Comparative results of leaching tests and biodegradation experiments showed a positive correlation between dissolved organic carbon and microbial activity. However, quantities of biodegraded or leached carbon are not representative of the samples' total organic carbon content. Thermal analyses in oxidizing conditions have revealed the presence of two fractions of organic components, showing different thermal behaviors. The associated mass losses were measured and compared to dissolved organic carbon. One of the two fractions can be directly linked to the leachable and easily biodegradable organic matter fraction. Calorimetric test is then presented as a novel analysis method that allows to provide rapid and global information concerning the characteristics of organic matter in bottom ash and its possible short and long-term evolution.

Keywords: Organic matter; Leaching; Biodegradation; Differential scanning calorimetry; Thermogravimetry

1. Introduction

Incineration of municipal solid waste (MSW) is widely used to face the problem of the large volume of waste that a modern society produces. Since MSW contains a relatively high percentage of organic compounds, such as papers, plastics, woods and garbage, the huge amount of waste is reduced by 90% (v/v) by incineration (Hjelmar, 1996). A major objective of MSW incineration is the complete mineralization of the organic constituents (Brunner et al., 1987; Belevi et al., 1992). But this objective is not achieved yet and the total organic carbon (TOC) content of the solid residues ranges between 2 and 50 g kg^{-1} (Belevi et al., 1992; Ferrari et al., 2002). The present study focuses on bottom ash, accounting for 80% (w/w) of the residual solid waste. New legislation in France has restricted the disposal of these residues since 2002. Consequently, they are increasingly being reused. In most cases, they are used as a component in several civil construction materials, such as concrete or in road construction (unbound sub-base layer) (Wile, 1996; Show et al., 2000; Hjelmar et al., 2006). The main problem related with the use of bottom ash is the direct or indirect harmful effect to the environment and human health (Sabbas et al., 2003): it contains varying amounts of heavy metals (Chimenos et al., 1999; Chang et al., 2001; Thipse and Dreizin, 2002) and also organic matter (Johansson and van Bavel, 2003). Organic carbon represents a potential source for chemical and microbiological processes. Indeed, it can provide a substrate for microbial activity and its biodegradation could influence the short and long-term behavior of the bottom

* Corresponding author. Tel.: +33 4 72 43 81 94; fax: +33 4 72 43 87 17.
E-mail address: gaelle.ducom@insa-lyon.fr (G. Ducom).

0045-6535/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.chemosphere.2006.11.054

ash in landfill or after reusing. In laboratory experiments, it has been shown that the organic carbon in bottom ash can be biodegraded even under alkaline conditions (Belevi et al., 1993; Rendek et al., 2006a). It has also been proved that the content of organic components such as water extractable organic carbon, amino acids, hexosamines and carbohydrates decreases during storage (Quilici et al., 2004; Zhang et al., 2004). Microbial degradation could result in the mobilization of some organic compounds and heavy metals. For instance, the role of dissolved organic carbon (DOC) in the enhanced copper leaching has been identified (Meima et al., 1999; van Zomeren and Comans, 2004; Arickx et al., 2006; Astrup, 2006).

Studies concerning organic matter in bottom ash mostly involved the determination of TOC content, DOC content from extractions with distilled water, and scarcely the characterization of organic compounds (Belevi et al., 1992; Dugenest et al., 1999; Lapa et al., 2002; Guimaraes et al., 2005). In France, a directive defines a leaching test and the maximum resulting DOC, and prohibits reuse of the bottom ash that could in the long-term damage the environment. However, in order to achieve a better insight in the influence of organic carbon on the short and long-term behavior of bottom ash, more information is needed on potential microbial activity. The aim of this study is a better understanding of organic matter evolution. So, we develop an original methodology to characterize organic matter based on different approaches (physico-chemical tests and biodegradation experiments). Then we propose a rapid assessment test of bottom ash quality.

2. Material and methods

2.1. Bottom ash samples

Bottom ash samples were taken from five distinct solid waste incineration facilities in France. Samples were abbreviated as BA1, BA2, BA3, BA4 and BA5. The five plants incinerate between 5000 and 150 000 t y^{-1} of waste (mainly MSW) and discharge between 800 and 35 000 t y^{-1} of bottom ash. The incineration properties were almost the same for samples BA1, BA2, BA3 and BA4 since those plants are equipped with the same type of mobile grate furnace. As for sample BA5, it was taken at the exit of a rotary kiln. The temperature in the combustion chambers was about 850 °C.

About 80 kg of freshly quenched bottom ash was taken from each facility. Each sample was dried at ambient temperature over four d to reach a final moisture content level of 5% (w/w). It was then passed through a 4 mm sieve. The remaining fraction was crushed until its grains passed through the 4 mm sieve and the totality of the sample was homogenized. It was stored at 4 °C prior to experiments.

2.2. Chemical composition

The chemical composition of bottom ash was analyzed after digestion with lithium metaborate followed by acid attack. Major elements were analyzed by inductively coupled plasma atomic emission spectroscopy (Jobin Yvon JY 70). TOC content was determined using a carbon analyzer LECO SC 144 DRPC after the decomposition of carbonates by an HCl attack and combustion at 1400 °C.

2.3. Accelerated ageing

In order to study bottom ash in similar conditions (pH, carbonation degree, ...), the samples were artificially carbonated prior to all the experiments. The accelerated carbonation of samples was performed at room temperature and a CO_2 pressure of 100 kPa. The reactor consisted of a metallic cylinder of 150 ml internal volume connected to an industrial grade CO_2 container.

About 100 g of MSW incinerator (MSWI) bottom ash was weighed and introduced in the vessel. After removing the air initially present in the chamber, the CO_2 pressure was established. The sample weight was monitored until it stabilized, that is to say until the end of the carbonation reaction. This set up has already been investigated and described by Rendek et al. (2006b).

2.4. Dissolved organic carbon (DOC)

DOC was estimated from a leaching test: 100 g of dry material was stirred in 1 l distilled water for 16 h (triplicate). This test is based on the French standard NF X31-210 (AFNOR, 1992), which consists in three consecutive similar extractions. After filtration through a 0.45 μm membrane, DOC content in the eluates was measured using a carbon analyzer Shimadzu 5000A.

2.5. Biodegraded organic carbon (BOC)

2.5.1. Respiration tests principle

Tests were carried out using an OxiTop® control system. This system consists of a 1 l bottle containing the bottom ash sample, hermetically sealed and equipped with a pressure-measuring head. A beaker containing a solution of sodium hydroxide (0.1 M) is placed in the bottle. This set up has already been introduced by Rendek et al. (2006a). It is described for a second time in this paper in order to make the understanding easier.

During the aerobic biodegradation of organic matter, microorganisms consume O_2 and CO_2 is released. Since bottom ash samples have been previously saturated in carbon dioxide in the accelerated ageing set up, no reaction occurs between the sample and the produced CO_2. Consequently, CO_2 is trapped in the sodium hydroxide solution.

During experiments, since O_2 is consumed and CO_2 is trapped, the pressure decreases in the bottles. This pressure decrease is monitored with the measuring head. The initial pressure in each bottle is the atmospheric pressure (101.3 kPa), which corresponds to an O_2 partial pressure of 21.0 kPa. This indicates that when the pressure decrease reaches 21.0 kPa, there is no oxygen left in the bottle, so it