Waste Management 44 (2015) 125–134

Contents lists available at ScienceDirect

Waste Management

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

Thermal and mechanical stabilization process of the organic fraction of the municipal solid waste

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ARTICLE INFO

Article history:
Received 2 February 2015
Revised 25 June 2015
Accepted 16 July 2015
Available online 21 July 2015

Keywords:
Organic waste
Drying
Volume reduction
Domestic appliance
Energy consumption

ABSTRACT

In the present study a thermo-mechanical treatment for the disposal of the Organic Fraction of Municipal Solid Waste (OFMSW) at apartment or condominium scale is proposed. The process presents several advantages allowing to perform a significant volume and moisture reduction of the produced waste at domestic scale thus producing a material with an increased storability and improved characteristics (e.g. calorific value) that make it available for further alternative uses. The assessment of the applicability of the proposed waste pretreatment in a new scheme of waste management system requires several research steps involving different competences and application scales. In this context, a preliminary study is needed targeting to the evaluation and minimization of the energy consumption associated to the process. To this aim, in the present paper, two configurations of a domestic appliance prototype have been presented and the effect of some operating variables has been investigated in order to select the proper configuration and the best set of operating conditions capable to minimize the duration and the energy consumption of the process. The performances of the prototype have been also tested on three model mixtures representing a possible daily domestic waste and compared with an existing commercially available appliance. The results obtained show that a daily application of the process is feasible given the short treatment time required and the energy consumption comparable to the one of the common domestic appliances. Finally, the evaluation of the energy recovered in the final product per unit weight of raw material shows that in most cases it is comparable to the energy required from the treatment.

1. Introduction

The organic waste represents a large portion of municipal solid waste ranging from about 30–65% (Modak et al., 2011) depending on the urbanization and the economic development in the different world geographic areas. When separated waste collection is performed, landfilling still represents the most common method used to dispose the Organic Fraction of Municipal Solid Waste (OFMSW). Even if landfills have reached a high level of maturity and complexity by performing energy recovery from gas capture, aerobic digestion, pre-composting of waste, landfill capping and composting, several concerns related to greenhouse gases (GHG) emissions (Oonk, 1994), leachate contamination and lands availability still exist. Moreover, CO_2 emissions from operational activities connected to the waste collection system have to be taken into account in the overall carbon balance of any disposal process. A correct management of wastes at domestic scale could be a viable alternative to the current centralized management system having beneficial effects on the operations of waste collection, storage and disposal.

Some domestic appliances have been already launched on the market even though their diffusion is somewhat limited. Some systems, known as garbage disposal unit (GDU), operate only a mechanical grinding prior to discharge the waste directly into the sewer system. Many studies have shown the convenience of the application of GDUs and they safe application also in highly urbanized areas (Department of Environmental Protection, NY City, 1997; Galil and Yaacov, 2001; Rosenwinkel and Wendler, 2001; Bolzonella et al., 2003; Diggleman and Ham, 2003; Marashlian and El-Fadel, 2005; Battistoni et al., 2007).

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http://dx.doi.org/10.1016/j.wasman.2015.07.026
0956-053X/

Nevertheless, they have raised environmental concerns about the addition of extra-loadings of pollutants in sewer systems and wastewater treatment plants.

Home composting units have been also commercialized going from open door composting bin to indoor appliance. The first option, not applicable in densely urbanized cities, if operated aerobically, has a very low environmental impact, whereas, if operated anaerobically, it releases significant quantities of GHG (Lundie and Peters, 2005). On the other side, the indoor devices given the reduced volumes require a daily use that is not compatible with the times required from the process.

In this paper a mechanical treatment coupled to a dewatering/drying process (Giudicianni et al., 2014) has been applied to treat at domestic scale the OFMSW. The process is aimed to the reduction of both the specific volume and the microbial activity of the waste thus producing a material with higher calorific value suitable to be stored for long periods and to be further used for energy production. While a thermal treatment at domestic scale requires the use of electricity, an analogous treatment at industrial scale could benefit of available thermal energy resulting more efficient. Nevertheless, the application of this process at domestic scale could represent a useful solution as it would provides the opportunity to have a not contaminated raw material directly available for Waste to Energy processes (WTE), avoiding, at the same time, formation of leachate, local production of GHG emissions and growth of pathogenic organisms. Moreover, by operating a volume reduction of the waste, the economic and environmental burdens associated to the operational activities connected to the transportation of the waste to the processing plants would be reduced. Some of the main factors determining the feasibility of such a pretreatment are related to the duration and the energy consumption of the process. In order to minimize these two parameters two configurations of a domestic appliance prototype have been proposed and compared and the influence of some operating variables on the treatment cycle has been evaluated. Odor compounds generation during the treatment represents an important issue but it is not addressed in this study given the difficulty to obtain a reliable and objective quantitative relation between odor volatiles concentration and odor detection by the human nose (Rappert and Muller, 2005). However, it is known from literature, that odors generated from the food processing plants are a mixture of various organic and inorganic compounds which are easily biodegraded (Rappert and Muller, 2005) and that generally the lowest toxic values of these compounds in air are at least a factor of 500 higher than the odor threshold values and consequently they are detected long before their concentration becomes a health risk (Mackie, 1984; Tamminga, 1992). However, the proposed food waste processing protocol performs a heating treatment at temperature at most equal to those typical of a cooking oven and, consequently, it produces similar volatiles compounds that can be treated with efficient solutions (such as activated carbon filters used in the kitchen exhausts) already commercially available.

In this paper a preliminary analysis has been carried out aimed to the definition of the process operating conditions through the evaluation of the influence of some operating variables on the prototype performances. Than three model mixtures of organic domestic waste have been processed and characteristic times and energy flows involved in the treatment cycle (energy consumption and energy recovery in the processed material) have been compared to the results obtained from a commercially available appliance. The collected results could represent useful data for a future analysis concerning the evaluation of the environmental and economical burdens associated with the process and the avoided burdens associated with economic activities which are displaced by materials and/or energy recovered from the waste.

2. Experimental set-up

2.1. Glossary

For the sake of clarity a short glossary with the most crucial terms in the context of this article is provided:

Cycle time: duration of the whole pressing/drying stage in the thermopress.
Pressing step: phase in which the whole pressing/drying stage in the thermopress is divided.
Energy consumption: integral of the measured electrical power consumption of the thermopress along the cycle time excluding the energy consumed during the interval (1 min) between 2 consecutive pressing steps.
Model waste mixture (WS): mixture of food and napkins residues typically present in the OFMSW exhibiting spongy (WS1), fibrous (WS2) or hard (WS3) characteristics.
Raw material: untreated model waste mixture fed to the grinding unit of the prototype or to the commercial food waste processor.
Grinded material: raw material recovered after the grinding stage and sent to the pressing/drying stage.
Processed material: grinded material after the pressing/drying stage.
Dried material: processed material deprived of its residual moisture.

2.2. Experimental equipment

In this study two experimental devices have been used for the tests. The first one is a prototype of an household dryer properly designed for the study of the proposed waste thermomechanical pretreatment process. The second device is a commercially available food waste processor capable to simultaneously grind, press and dry the waste. It is used as a reference for evaluating the performances of the thermopress prototype. It has been chosen as reference system because, at our knowledge, it is the only commercially available system that operates the same processes (grinding and drying) using a different technology. In the following we will refer to the commercial device as FWP. Both the prototype and the FWP will be described in details in the following subsections.

2.2.1. Prototype

On the ground of an extensive campaign of preliminary tests it has been decided to design the prototype of the organic waste pre-treatment system using a two-stage process. In the first stage a mechanical reduction of the size of the raw material has been performed. Then the grinded material has been pressed and dried, in a second stage.

Two configurations of the prototype have been considered using different system for the size reduction of the raw material: a commercial shredder and a Garbage Disposal Unit (GDU). The shredder is equipped with a system of opposed blades; the rotation of the blades conveys the waste through the blades themselves. The GDU consists of a turntable surrounded by a shredder ring, which has sharp slots. The food waste is placed on the turntable and through centrifugal force is forced to its perimeter and through the shredder ring. The turntable has a number of swiveling lugs that convey the waste through the shredder. The GDU requires the addition of a certain amount of water (about 5 l for 1 kg of waste). In the following we'll refer to the two configuration of the prototype as shredder and GDU configuration.