CHEMICAL ENGINEERING TRANSACTIONS

VOL. 37, 2014

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Guest Editors: Eliseo Ranzi, Katharina Kohse- Höinghaus
Copyright © 2014, AIDIC Servizi S.r.l.,
ISBN 978-88-95608-28-0; **ISSN** 2283-9216

DOI: 10.3303/CET1437105

Mechanical and Thermal Treatments of Municipal Solid Waste Organic Fraction in Small Dehydration Units

Paola Giudicianni*[a], Anna Ciajolo[b], Nicol Sferragatta[b], Antonio Cavaliere[a], Raffaele Ragucci[b]

[a]DICMAPI - Università degli Studi Federico II di Napoli - Italy
[b]Istituto di Ricerche sulla Combustione - C.N.R. Napoli – Italy
giudicianni@irc.cnr.it

Landfilling, composting and incineration represent the most common processes used for the disposal of organic fraction of municipal solid waste (OFMSW). The evaluation of the best available technology used for the exploitation of these processes has to take into account the environmental impact of the technology itself and of the connected activities in addition to peculiar local aspects related to lands availability, legal constrains and climatic conditions of the specific country. Different technological solutions and management strategies have been proposed aimed to reduction of Green House Gas (GHG) emissions and leachate release as well as to increase energy recovery efficiency of existing disposal plants.
The aim of the present study is to identify a feasible OFMSW disposal processing chain at apartment or condominium scale capable to perform a proper dehydration and volume reduction of the organic waste thus producing a material directly available for Waste to Energy processes. Four sub-processes have been identified: mechanical treatment, separation of the aqueous phase, drying and effluent gas treatment. The first three sub-processes have optimized on the basis of characteristic times, energy consumption and adaptability to domestic scale.

1. Introduction

The increasing worldwide production of Municipal Solid Waste has promoted in the last decade a continuous search for environmentally safe as well as socially and politically acceptable disposal processes and technologies. Pursuant to the data of World Waste Survey 2009 (Chalmin and Gaillochet, 2009), about 1.9 tons of MSW are produced every year and represent about 50 % on weight basis of total waste. A fraction ranging from 20 to 80% of MSW is made up of organic and fermentable waste (Chalmin and Gaillochet, 2009) depending on several factors related to the urbanization and the economic development. The most common methods used to dispose OFMSW are landfilling, composting and mass burn incineration, but the identification of the best available technology requires many factors to be taken into account, depending on environmental impact of decomposition and life-cycle activities processes, but also on the geographic configuration and the legal constrains of the specific country. As for the environmental aspect, landfill represents the major source of greenhouse gas (GHG) emissions determining the use of alternative forms of landfill management strategies such as energy recovery from landfill gas capture, aerobic landfilling, pre-composting of waste prior to landfilling, landfill capping and composting of the organic fraction of municipal solid waste. Nevertheless, energy recovery from landfills has an efficiency ranging from 50 to 100 % (Oonk and Boom, 1995) and also leachate contamination and lands availability still remain a serious problem. Also in the case of composting plants, different studies show that GHG emissions are not completely avoided producing a not negligible amount of CO_2e/ton of mixed waste (Jakobsen, 1994). Moreover, CO_2 emissions from operational activities connected to the process 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 desirable in order to simplify the following operations of collection, storage and disposal. The thermal stabilization of organic waste at domestic scale could provide the opportunity to have a not contaminated raw material directly available for WTE

Please cite this article as: Giudicianni P., Ciajolo A., Sferragatta N., Cavaliere A., Ragucci R., 2014, Mechanical and thermal treatments of municipal solid waste organic fraction in small dehydration units, Chemical Engineering Transactions, 37, 625-630
DOI: 10.3303/CET1437105

processes, avoiding, at the same time, formation of leachate, local production of GHG emissions, production of unpleasant odors and growth of pathogenic organisms. Moreover, a mechanical treatment of the waste aimed to its volume reduction, could allow the reduction of CO_2 emissions from operational activities connected to the transportation of the waste to the processing plants. Thermal treatments have been proposed to reduce moisture content of agricultural wastes have been proposed (San Josè et al., 2011).
The evaluation of the environmental burdens associated with the process requires the identification and quantification of energy used, wastes flows and avoided burdens associated with economic activities which are displaced by materials and energy recovered from the waste.
The aim of this work is to identify a combined mechanical and mild temperature treatment aimed to the reduction of the specific volume and of the microbial activity, producing a material with higher calorific value suitable to be stored for long periods and to be further used for energy production. In this study four sub-processes have been identified: mechanical treatment, separation of the aqueous phase, drying and effluent gas treatment. The analysis of the process has been carried out evaluating for each of the first three units the best technology and the optimal operating variables in terms of characteristic times, energy consumption and adaptability to domestic scale. Finally, the energy recovery from the final product has been evaluated.

2. Experimental

2.1 Materials selection

The selection of materials for experimental tests has been made following a bottom-up approach for the modelling of a typical domestic organic waste. Single components of a typical domestic organic waste have been selected. In order to choose the single components to be tested a classification of organic residues has been made taking into account their presence in a typical domestic organic waste and their main macroscopic physical characteristics such as thickness, hardness and presence of filaments. In Table 1 a classification of the selected materials has been reported with some example of category representatives. In this study, only experimental tests on the vegetal fraction of organic waste have been carried out and one or more vegetal residue for each of the first 3 categories of the proposed classification has been tested. The refuse of the following foods have been selected:

- Category 1: skins of apples and kiwi, scraps of lettuce;
- Category 2: peels of oranges, waste broccoli, bread;
- Category 3: peels of banana, pods of peas;

Table 1: Classification of typical food organic waste

	Fruits	Vegetables	Carbohydrates	Meat
thin (about 0.5 mm) and soft	skins of apples, kiwi, figs, persimmons, peaches	scraps of lettuce, potatoes, carrots, cucumbers	pasta, rice	-
thick (about 5 mm) and medium hardness	peels of oranges, mandarins, melons, pineapple	waste broccoli, artichokes, cauliflower, pumpkin	bread	fat
filamentous	banana peels	pods of peas and beans, fennel	-	-
high hardness	peach pits, apricot, olive	-	-	bones

2.2 Experimental apparatus and products analysis

In the present paper the analysis of mechanical and thermal treatments has been carried out. To this aim two different commercial devices for both sub-processes have been evaluated. As for mechanical treatment the following equipment have been considered:

- A waste-shredder (EGO23000X, Electrolux);
- A press;
- An under-sink waste disposer (ECO706, NTA).

The shredder is equipped with a system of opposed blades. The press is made up of a circular plate capable to exert 0.5 MPa on the bottom of a perforated cylinder equipped with a cylindrical gutter. The under-sink waste disposer 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 experimental procedure requires that 300 g of raw material be introduced into the treatment system. The under-sink waste disposal unit operates with the addiction of water. In this case, processed waste is collected onto a 400 μm mesh sieve placed at the exit of the device in order to allow a preliminary separation of the water and to limit the loss of material with the process water. A percolation time of 30 min before material collection and drying has been chosen. A dimensional analysis of the material lost in the percolation has been carried out filtering the percolated suspension at 8 and 1.2 μm and drying the filtered residue. The material obtained from the mechanical treatment was weighed and dried except for the case of the press that is coupled to the heating system. Two heating systems have been selected:

- Microwave oven (SAM 255, CEM), power=650 W;
- Heating plate (F70, Falc), power=430 W.

The operating conditions of the drying systems have been defined by monitoring the treatment times and energy consumption of the process varying the oven temperature and, only in the case of the microwave oven, the emitted power. The treatment time and the intrinsic moisture of the treated material have been evaluated by running consecutive drying steps and monitoring the weight loss rate. Drying process has been considered ended when the weight loss rate became less than 0.02 wt%/min. The energy consumption, measured with an amperometric clamp and a data collection dedicated processor, has been evaluated by running a continuous process for a time equal to the time of treatment obtained by the step process. Mechanical and thermal sub-processes have been coupled as indicated in Table 2.

Table 2: Coupling of selected sub-processes.

	Shredder	Undresink waste disposer
Microwave	TM	DM
Thermopress	TTP	DTP

3. Results and discussion

3.1 Mechanical treatment

In this section the selected mechanical treatment devices have been compared in terms of device management, the characteristic size of the processed materials and weight variation of the material before and after the treatment.
The shredder allows the feeding of a fixed volume of waste that is processed in a short-lasting cycle (about 2 min). The feeding stage doesn’t require any manual operation. After treatment the material retains its original characteristics resulting in particle characteristic size of 1 cm (order of magnitude); this system allows the treatment of small bones, but not of material characterized by high hardness (e.g. fruit pits). The shredder doesn’t require the use of water during the treatment resulting in a negligible weight variation of the material after being processed (weight losses lower than 5 % are due to waste residues sticking on blades surface).
The under-sink waste disposer operates continuously and it requires a slow feeding with the addition of water to avoid turntable jam. It determines a considerable reduction of the size of the raw material. This equipment is able to mill both small bones and material of greater hardness. Nevertheless, the addition of water entails an increase of weight of the raw waste depending on the structural characteristics of the material. Percolation of the milled material carried out on 400 μm mesh sieve for a period of 30 min shows that all the tested materials present a weight increase of 10 % with respect to the initial weight except for spongy materials like banana peels (+43 wt%), orange peels (+150 wt%) and bread (+200 wt%) whose weight increase is considerably larger; only scrap of lettuce show a weight loss of 15% during mechanical treatment.
Dimensional analysis of percolated material has been carried out on two selected wastes, scraps of lettuce and orange peels, given their extreme behaviour during mechanical treatment. The percentages of the total dry matter recovered from the 400 μm filter are 43 wt% and 39 wt% for scraps of lettuce and orange peels, respectively. However, the most abundant fraction of the lost material has a size smaller than 1.2 μm: 49 wt% of total dry material for scraps of lettuce and 40 wt% for orange peels. Leaving only a small fractionof the dry material in the size range between 1.2 and 400 μm.
Finally, both the shredder and the under-sink waste disposer are characterized by a negligible energy consumption (about 0.009 kWh).

3.2 Thermal treatment

The results obtained with the microwave oven are discussed first, than results obtained with thermopress will be presented. A preliminary study has been carried out aimed to the choice of the optimal operating conditions of the oven by varying power emitted by the magnetron and operating temperature for microwave drying device and operating temperature for heating plate of thermopress. In Figure 1 the energy consumption as a function of treatment time at different powers (P) and temperatures (T) has been reported for apple peel processed in both TM and DM system. For the TM system a temperature of T=343 K has been fixed since at higher temperatures local superheating cause the onset of combustion reactions. Treatment time and energy consumption do not vary significantly with the power in the range 605-390 W, while they increase for P < 390 W. The optimum operating conditions, since at lower temperature it has been verified that the drying time is much longer, correspond to T=343 K and P=325 W. For the DM system the optimum operating conditions are recorded for T=373 K and P=650 W. In these conditions there is a reduction of energy consumption > 6% and a reduction of the drying time of about 20 % compared to the other tested conditions.

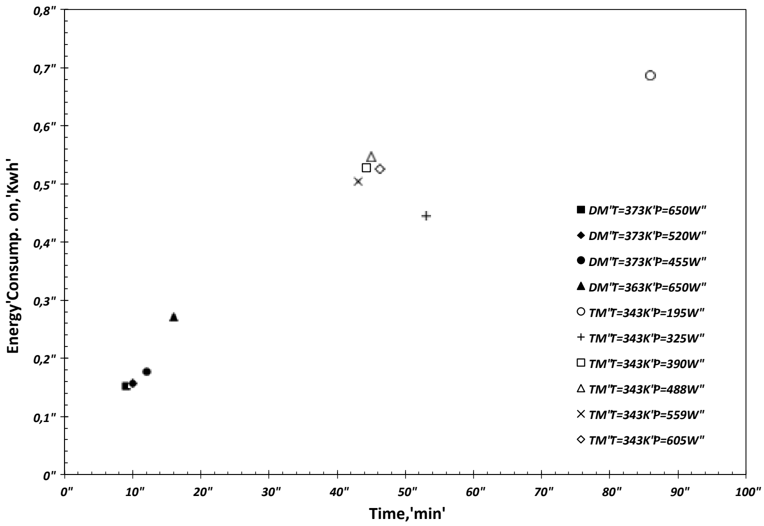

Figure 1 Energy consumption as a function of treatment time at different powers and temperatures for apple peel processed in both DM and TM system

Concerning the test with the thermopress, the optimal operating temperature for heating plate was set at 423 K because no substantial differences has been observed in the drying times and energy consumption in the range 373-473 K in both cases of mechanical treatments.

In Figure 2 the weight loss as a function of treatment time for different wastes processed in the system TM has been reported. In the case of DM system in the early stages of the process the weight loss curves of all the tested wastes overlap, while they differ significantly in the final drying stage when water loss is highly dependent on mass transfer phenomena inside the material and consequently on its physical properties. Drying times and energy consumption of the TM system has been evaluated and reported in Table 3.

Treatment time as well as the energy consumption varies considerably depending on physical properties of the considered material and not on its moisture content: for example, drying time of pea pods and banana peels is equal respectively to 50 and 85 min in spite of their similar moisture content (respectively 88 and 89 %). This can be explained by observing that the material after treatment with the shredder retains its original structure and this has a significant effect on the duration of the process and on the relative power consumption.

Two materials presenting very different behavior in the TM system, scraps of lettuce and oranges peels, have been tested in the DM system and a comparison between characteristic drying times and energy consumption have been provided in Table 3, while in Figure 1 the weight loss curves are presented. The treatment with the under-sink disposal unit (DM), reduces wastes structural differences and increases their water content with free water that evaporates just in the first stage of the drying process. As it can be seen from table 4, again the drying time are very different for the two tested materials, but in the case of TM system moisture content of the raw material and its physical properties are less relevant with respect to the added water that determines process duration.

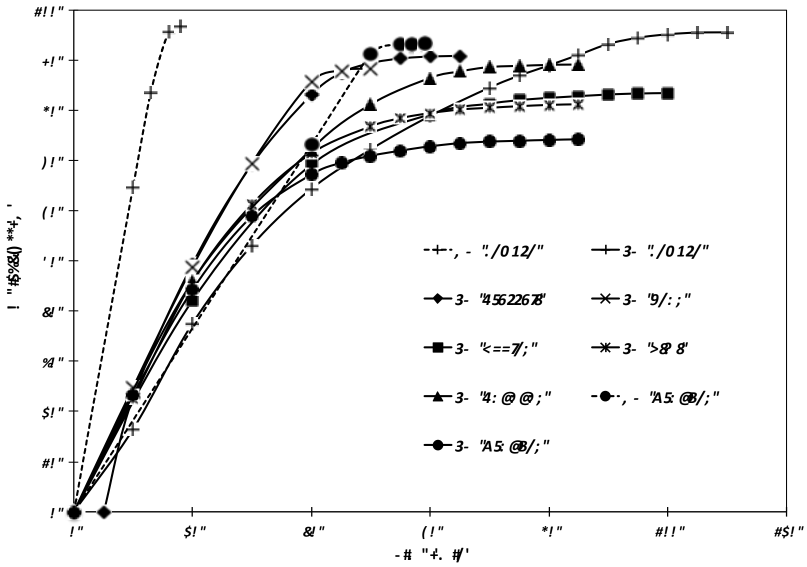

Figure 2: Weight loss as a function of treatment time for different wastes processed in the system TM, DM

Table 3: Drying time and energy consumption for DM system

	Weight loss, wt%	Drying time, min	Energy consumption, Kwh
Broccoli waste	92.0	65	0.68
Scraps of lettuce	96.0	110	1.03
Pods of pees	88.1	50	0.61
Skins of apple	83.0	100	0.95
Skins of kiwi	80.0	85	0.65
Bananas peels	89.4	85	0.73
Orange peels	74.8	85	0.69

It should be noted that a comparison between TM and DM system is affected by the different operating temperature and power of the two system, nevertheless, it can be observed that in their optimal operating conditions the performance of TM system are better with respect to DM system for the spongelike materials responsible of a huge increase of weight of the raw material due to the addiction of water during the mechanical treatment.

Table 4: Comparison between TM and DM system

	System	Drying time, min	Energy consumption, Kwh
Scraps of lettuce	TM	110	1.03
	DM	22	0.40
Orange peels	TM	85	0.69
	DM	59	1.02

Performance of microwave heating in drying process has been compared with performance of thermopress. Both mechanical treatments have been applied to the raw materials before drying test. In order to compare the two heating systems a reduced time Tr has been defined as the time required to reduce to a maximum of 8 % of the original waste mass the water content of the material. This moisture limit has been taken equal to the typical moisture content of biomass pellets for household stoves. In Table 5 reduced drying time and energy consumption of TTP and DTP have been compared to the corresponding values for TM and DM. In both cases of TTP and DTP reduced trying time is very different for the two materials, mainly in the case of TTP system in which reduced drying time obtained for orange peels is four times higher than the one required for scraps of lettuce. This is due to the very different bed height of pressed material that determine in the case of orange peel a slower heating of the whole bed due to higher conductive transfer resistance. The differences in height of material bed are reduced in the case of DTP system and consequently also the differences in Tr are reduced. Comparison between microwave heating and thermopress highlights that, for both waste shredder and under sink disposer mechanical treatments, even if reduced drying times required from thermopress are higher, the total energy consumption is significantly lower.

Table 5: Performance of microwave and thermopress heating devices

	System	Tr, min	Energy consumption, Kwh
	TM	87	0.63
	TTP	47	0.22
	DM	15	0.27
Scraps of lettuce	DTP	23	0.12
	TM	40	0.40
	TTP	196	0.48
	DM	47	0.89
Orange peels	DTP	57	0.20

4. Conclusions

The obtained results indicate that, if the mechanical treatment does not alter the characteristic size of material, drying time is highly dependent on material physical properties. Nevertheless, to obtain a very uniform and fine sludge there is a significant amount of water, used to help in the shredding process, that remains embedded in the case of spongelike materials. This requires more energy and longer times for the drying process. Moreover, in this case there is a significant amount of biomasses that is drained away by the water used to help in the shredding process. On the other hand these systems are capable of treating a large variety of materials including those very fibrous and hard producing an almost uniform sludge and if used in coupling with thermopress determine significant reduction of the energy required for the drying process.

References

Chalmin P., Gaillochet C., 2009, From Waste to Resource: an abstract of World Waste Survey 2009, ed. Economica, Paris, France.

Oonk J., Boom A., 1995, Landfill gas formation, recovery and emissions, Cost-effectiveness of alternative strategies in mitigating the greenhouse impact of waste management in three communities of different size, Mitigation and Adaptation Strategies for Global Change 2, 337-358.

San Josè M.J., Alvarez S., Lòpez L.B. Garcìa I., 2011, Drying of Mixtures of Agricultural Wastes in a Conical Spouted Bed Contactor, Chemical Engineering Transaction, 24, 673-678.

Jakobsen S.T., 1994, Aerobic decomposition of organic wastes: I. Stoichiometric calculation of air change. In ROU (Recycled Organics Unit). 2007. Greenhouse Gs Emissions from Composting Facilities. <www.recycledorganics.com>, Accessed 25.07.2013.