Bioresource Technology 182 (2015) 217–224

Contents lists available at ScienceDirect

Bioresource Technology

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

# Hydrothermal carbonization of off-specification compost: A byproduct of the organic municipal solid waste treatment

Daniele Basso [a], Elsa Weiss-Hortala [b], Francesco Patuzzi [c], Daniele Castello [a], Marco Baratieri [c], Luca Fiori [a,*]

[a] DICAM, Department of Civil, Environmental and Mechanical Engineering, University of Trento – via Mesiano 77, 38123 Trento, Italy
[b] Université de Toulouse, Mines Albi, CNRS, Centre RAPSODEE, Campus Jarlard, F-81013 Albi Cedex 09, France
[c] Faculty of Science and Technology, Free University of Bolzano – Piazza Università 5, 39100 Bolzano, Italy

## HIGHLIGHTS

- HTC of off-specification compost at 180, 220, 250 °C and 1, 3, 8 h reaction time RT.
- The increase in hydrochar HHV with respect to raw feedstock from 7% to 61%.
- Hydrochar elemental composition similar to that of peat and lignite for $T = 250$ °C.
- Hydrochar thermal stability greatly increased at $T = 250$ °C and at $T = 220$ °C when RT = 8 h.
- HTC results were highly dependent on *T*, while the effect of RT was much lower.

## ARTICLE INFO

*Article history:*
Received 6 November 2014
Received in revised form 23 January 2015
Accepted 28 January 2015
Available online 4 February 2015

*Keywords:*
Hydrothermal carbonization
Hydrochar
Organic waste
Municipal solid waste
Biofuel

## ABSTRACT

The possibility to apply the hydrothermal carbonization (HTC) process to off-specification compost (EWC 19.05.03) at present landfilled was investigated in this work. The aim was to produce a carbonaceous solid fuel for energy valorization, with the perspective of using HTC as a complementary technology to common organic waste treatments. Thus, samples of EWC 19.05.03 produced by a composting plant were processed through HTC in a batch reactor. Analytical activities allowed to characterize the HTC products and their yields. The hydrochar was characterized in terms of heating value, thermal stability and C, H, O, N, S and ash content. The liquid phase was characterized in terms of total organic carbon and mineral content. The composition of the gas phase was measured. Results show that the produced hydrochar has a great potentiality for use as solid fuel.



## 1. Introduction

Nowadays, the need for clean and renewable energy is a strong and relevant issue worldwide. The shortage of fossil resources and the concern for the state of the environment have boosted the attention towards the development of new energy sources, which could reduce or even substitute fossil ones. Among them, biomass, both virgin and residual, is one of the most suitable candidates. Indeed, when handled in a proper way, biomass is fully renewable and, at the same time, it is able to reduce net carbon emissions. The strong interest by both policy makers and the majority of the population is a strong driving force for the investigation of new and affordable technologies.

Hydrothermal carbonization (HTC) has the potentialities to meet these requirements. HTC is a thermochemical conversion process, consisting in reacting wet organic substrates (i.e. with a moisture content even higher than 80 wt.%) at hydrothermal conditions, that is in hot pressurized liquid water. Process conditions are quite mild: temperatures range between 180 °C and 250 °C and pressures are those required to maintain water at liquid state (10–40 bar). Typical residence times range between a few to several hours. Hot pressurized water exhibits a higher ion product than at ambient conditions, behaving as an acid/base catalyst precursor and acting as both a solvent and a reactant (Kruse and Dinjus, 2007). Such peculiar properties result in a very reactive behavior, which is able to promote the transformation of the organic matter and its enrichment in carbon. The main product of the process is called hydrochar, a carbonaceous solid with a carbon content usually higher than 80 wt.%. Its chemical composition

* Corresponding author. Tel.: +39 0461 282692.
*E-mail address:* luca.fiori@unitn.it (L. Fiori).

http://dx.doi.org/10.1016/j.biortech.2015.01.118
0960-8524/

is very similar to low rank coals, such as peat or lignite (Schuhmacher et al., 1969). The interest on hydrochar is motivated by the wide range of potential applications it could have: as a solid fuel (Lu et al., 2011; Hwang et al., 2012; Román et al., 2012; Castello et al., 2014), as a soil improver (Berge et al., 2011), as a sorbent (Demir-Cakan et al., 2009), as a highly functionalized carbon material (Titirici and Antonietti, 2010), or as an activated carbon precursor (Unur, 2013). Up to now, HTC process has been widely studied by many authors (Funke and Ziegler, 2010; Libra et al., 2011; Stemann et al., 2013).

The typical process parameters, such as the temperatures and the pressures involved, and the type of products obtained make HTC interesting for several industrial applications. With respect to other thermochemical processes, such as supercritical water gasification (Fiori et al., 2012), a HTC plant would require much reduced investment and operating costs, as well as easier solutions to face safety issues. Moreover, if compared to common organic waste treatments (e.g. composting or anaerobic digestion), HTC involves much lower residence times, which would result into reduced volumes of the equipment. HTC is also capable of managing possible variations of the chemical and physical characteristics of the input feedstock, which would be detrimental for biochemical processes. This is a crucial aspect when dealing with waste materials, which usually present a high grade of heterogeneity. Therefore, to date, many authors have studied the possibility to exploit hydrothermal carbonization for organic waste management and treatment (Berge et al., 2011; Hwang et al., 2012; Liu and Balasubramanian, 2012; Lu et al., 2012).

Nevertheless, in all these works the substrate was treated "as it is". HTC has thus been regarded as a possible substitute for the state-of-art biochemical technologies for organic waste treatment. In the present study, a completely novel approach was followed. Indeed, HTC was not investigated as a stand-alone process, but as a complementary treatment for the organic fraction of municipal solid waste (OFMSW), capable to enhance the whole efficiency of the waste management and treatment chain. In the region where the research group operates (i.e. North-Eastern Italy), at present the disposal of the OFMSW is accomplished through composting. However, not all the materials produced from the composting process are eligible to be used as fertilizers. Indeed, the regulations state that the bio-stabilized organic matter can be accepted as agricultural compost only if its size is lower than 10 mm. The fraction that does not meet such requirement is named "off-specification compost" (hereinafter referred to as OSC) and it is coded by the European Waste Catalogue (EWC) as EWC 19.05.03. This material is currently discarded and landfilled, with further costs. The amounts are non negligible, as they represent around 3% of an OFMSW composting plant throughput.

This work focuses on the application of HTC to OSC. Such process could be highly beneficial, since it allows obtaining both a reduction of the amounts of waste sent to landfills and the production of a valuable energy carrier. Additionally, an integrated HTC/composting process is potentially more advantageous with respect to a fully HTC-based process. As a matter of fact, it would be preferable to obtain compost for agricultural use, while choosing a mere energy valorization only for that fraction of composted material which is not able to meet law prescriptions to be considered as a fertilizer. Therefore, the envisaged integrated process would maximize the benefits of both technologies and it could potentially lower the overall cost for waste disposal.

In the present study, batch HTC tests involving OSC were carried out at different temperatures and residence times. Gaseous, liquid and solid products were collected and fully characterized. Considerations about the utilization of the produced hydrochar as a solid fuel were traced.

## 2. Methods

The experimental activities performed in this work involved the utilization of OSC, a feedstock coming from OFMSW composting, which was utilized to feed a bench-scale HTC batch reactor. In the present sections, details about the feedstock, the apparatus and the experimental and analytical procedures are provided.

### 2.1. Feedstock characteristics

The feedstock was provided by the company Contarina S.p.A., which operates a composting plant in North-Eastern Italy. Here, the organic waste undergoes bio-oxidation and post-maturation processes at aerobic conditions. Afterwards, the bio-stabilized material is sieved and the fraction with a particle size larger than 10 mm is discarded, being it not compliant with law specifications. Such fraction is defined as "off-specification compost" (EWC 19.05.03), OSC for brevity. As regards the composition, the feedstock is mainly composed by ligno-cellulosic materials and stabilized organic materials.

Due to its high heterogeneity, OSC was milled by a grinder (Sunbeam Osterizer blender) to homogenize the samples as much as possible, before the HTC process. Subsequently, several 10 g samples were collected and stored in a freezer at −24 °C until use. The substrate was fully characterized: see Table 2 in Section 3.4.

The moisture content of the raw substrate was experimentally measured by drying 5 samples of substrate at 105 °C in an oven for 8 h. The difference between the initial weight of the samples and their weight after drying allowed the determination of the moisture content (30.3% ± 0.1). Details about the other analytical procedures utilized for feedstock characterization are reported in Section 2.3.

### 2.2. HTC apparatus and experimental procedure

A HTC experimental apparatus was designed and constructed. It consisted of a stainless steel (AISI 316) batch reactor with an internal volume of about 50 mL. The reactor was designed for a maximum temperature and pressure of 300 °C and 140 bar, respectively. Fig. 1a shows the piping and instrumentation diagram (P&Id) of the experimental system.

Two piping lines (internal diameter: 2 mm) were connected to the reactor. Referring to Fig. 1a, the left pipe ended with a needle valve (named V1). Along this pipe, a pressure transmitter (PT) and a pressure gauge (PI) were placed. Between the main pipe and the PI, a rupture disc (rupture pressure = 120 bar) was placed for safety reasons. One end of this pipe was connected to a rubber hose, through which an inert gas ($N_2$) was fluxed to purge the reactor from the presence of air, before the beginning of each HTC test. To prevent the contact between hot fluids from the reactor and the PT or the PI, the pipe was forced to pass through a water bath. The right pipe was intended to evacuate the gaseous products formed during the carbonization, once the experimental run was terminated. Another needle valve (V2) guaranteed the closure of the reactor, while performing the HTC run. The right pipe was also connected to the apparatus used for both the measurement of the gas volume and the GC analyses. Finally, a double thermocouple (TT) was embedded inside the reactor, passing through the reactor flanged cover. The thermocouple was positioned to detect the temperature near the center of the inner volume of the reactor. Both the thermocouple and the pressure transmitter sent data to the HTC control panel, which supplied temperature and pressure data to a temperature recorder (TR) and to a pressure recorder (PR), respectively. The HTC temperature indicator and controller (TIC) was connected to a band heater, in order to heat the reactor and