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Torrefaction of tomato industry residues

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HIGHLIGHTS

- Torrefaction of tomato peels was studied.
- Temperature results more significant than residence time.
- Up to 30% of the mass was lost with an energy densification increment of about 20%.
- Torrefaction produces high carbon content fuel-like material.
- Results suggest the application of a mild torrefaction.

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ABSTRACT

The standardization is an important aspect for fuel products. Some residual biomass are highly heterogeneous making their energy use rather difficult. Torrefaction can represent an interesting process to improve the standardization and quality of the lignocellulosic biomass. In the present research torrefaction has been applied on tomato peels, an important Italian industry residue. Different residence times and torrefaction temperatures have been employed in a bench top torrefaction reactor. Proximate, ultimate, thermogravimetric and infrared analyses of raw and torrefied material have been performed to evaluate the influence of the process. From the mildest condition studied to the most severe one, mass yield, energy yield and energy densification vary in the ranges of 94.7–69.9%, 98.0–86.0% and 1.04–1.23 respectively. According to mass and energy yields, ultimate analysis and thermogravimetric profiles, temperature parameter results more significant than residence time. Torrefaction makes the material increasingly hydrophobic as torrefaction temperature increases. This results in a more biologically stable and standardized material suitable to be employed as fuel for energy application. The results of this paper provide useful indications and suggest a mild torrefaction.

1. Introduction

Biomass is an important renewable energy source as a way to reduce net CO_2 emission contributing to climate change mitigation. The use of biomass wastes for energy purposes, in particular, is considered one of the most interesting solutions by policy makers and scientific community to achieve this goal. In this case, in fact, in addition to the CO_2 reduction, the waste becomes a raw material for other processes avoiding waste disposal problems. However, energy use of the biomass wastes is often difficult due to several drawbacks: heterogeneity of material; high moisture content; poor biological stability; low energy density. To overcome these issues a pre-treatment is necessary and currently there is a high interest in the torrefaction process.

Torrefaction, a mild pyrolysis, represents a thermochemical process that consists in treating biomass at relatively low temperature (200–300 °C) under an inert atmosphere such as nitrogen. Heat provides the energy needed for breaking chemical bonds of the organic molecules, mainly cellulose, hemicellulose and lignin, leading to a change of the biomass structure with the production of volatile and liquid compounds (tar) together with the solid torrefied product. This process causes in the wood, and generally in ligno-cellulosic materials, very interesting changes for a biofuel production: the energy density increase, the strong hygroscopicity decrease [1] and the ease of grinding [2] are some of the most important aspects and an example of how the torrefied material approaches the behavior of a traditional solid fossil fuel [3,4]. The best properties of the torrefied material determine benefits in terms of energy densification, ease of grinding and biological stabilization, with cost reduction in specific production chain steps where costs are a function of the volumes involved like, for

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Abbreviations

TG	thermogravimetric curve
DTG	first derivative thermogravimetric curve
CP	crude protein
EE	ether extract
NDF	neutral detergent fiber
ADF	acid detergent fiber
ADL	acid detergent lignin

Notations

Tt	torrefaction temperature (°C)
Rt	residence time (min)
M_Y	mass yield (%)
E_Y	energy yield (%)
I_{ed}	energy densification index
LHV	low heating value (kJ kg^{-1})
A	ash mass content (% d.b.)

example, transport and storage. Another advantage is the possibility to mix the torrefied product with coal for the supply of power plants [5–7]. It was also noticed by different authors an energy advantage of performing torrefaction as pretreatment of biomass to be used in gasification [8–10].

Many authors have focused their attention to the torrefaction of woody biomass [1,6,11–13] but only few of them made researches on agricultural and food industry residues. Since these kind of materials are more heterogeneous than the woody ones and often not suitable for a direct energy valorisation, then torrefaction process can be a useful solution to overcome this issue. Wang et al. focused their attention on the torrefaction of rice husks employing microwaves [14]. Uemura et al. [15] described the effect of torrefaction on the basic characteristics of agricultural biomass wastes in Malaysia, such as empty fruit bunches, mesocarp fiber and kernel shell as a potential source of solid fuel. Shang et al. conducted torrefaction studies on wheat straw at batch scale reactor [16]. Chen et al. [17] carried out an experimental analysis on property and structure variations of agricultural wastes undergoing torrefaction such as coffee residue, sawdust and rice husk.

No specific studies have been carried out on tomato industry residues, a material quantitatively important at European level and in particular at Italian level.

Within the European agri-food sector, tomato paste manufacturing industry represents one of the main food industry [18]. Every year it generates a big amount of tomato residues, in many cases considered as wastes, responsible of disposal problems and environmental pollution. As reported by the authors in a previous paper [19], the World Processing Tomato Council (WPTC) argues that, between 2008 and 2010, Members in Mediterranean Region (AMITOM) have processed about 15.5 Tg of tomato, with Italy contributing for almost 5.0 Tg, corresponding to a potential of 1.2 Tg of residual material in Europe.

Currently, tomato processing residues, especially peels, do not generate so many benefits for industries, in particular for storage and preservation issues. In fact, the accumulation of these residues, predominantly in the warm periods, promotes uncontrolled anaerobic fermentations leading to environmental problems. To avoid added costs related to disposal process, tomato manufacturing companies often give their production residues for free to other companies that generally use them for feeding livestock [20,21] or in agriculture as soil amendment [22]. However Rossini et al. highlight a good energy content of tomato peels that could make the energy valorisation interesting [19].

For this reason, the present work aimed at investigating the effects of the torrefaction treatment on physical–chemical properties of the tomato peels by means of a bench top reactor. The effects of torrefaction temperature and retention time on mass and energy yields were investigated. Moreover, a deep characterization of raw and torrefied materials has been carried out by proximate, ultimate, thermogravimetric and infrared analyses. Finally, the hydrophobic behavior of treated and untreated materials was evaluated through moisture uptake tests.

2. Materials and methods

2.1. Introduction

The raw biomass, constituted by tomato peels, was obtained from an Italian tomato industry residue as described by the authors in a previous paper [19]. After separation and oven drying, peels were grinded in a cutting mill (mod. SM 2000, RETSCH) and the particles size between 0.25 and 1.00 mm was selected. The experimental work was then performed through the following steps:

- thermogravimetric analysis of tomato peels to define torrefaction temperatures (Tt).
- torrefaction tests in a bench top reactor (Fig. 1).
- physicochemical characterization of raw and torrefied materials (proximate, ultimate, thermogravimetric and infrared analyses). A single analysis of crude protein (CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) has been carried out to better understand the typology of raw material studied in the paper.
- moisture uptake tests to compare hydrophobic behavior of raw material, torrefied products and coal as fossil fuel reference.
- data processing.

The work is described in detail as follows.

2.2. Thermogravimetric analysis

The thermal behavior of the raw and torrefied biomass was studied by means of thermogravimetric analysis, which was carried out

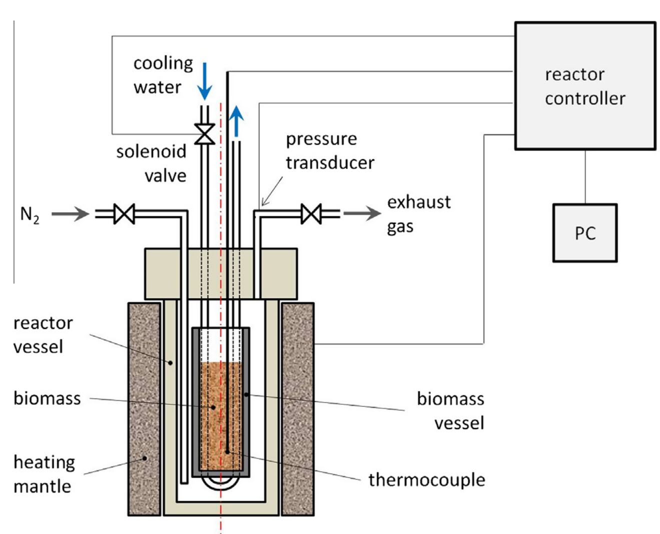

Fig. 1. Scheme of the bench top torrefaction reactor employed.