Experimental investigation of controlled thermal degradation of unconventional fuels

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Abstract
This work presents an experimental investigation of the direct combustion process of unconventional fuels, focusing on the tuning of main parameters (oxygen content in the gas feed, heating rate and bed porosity). The main objective of this paper is to evaluate the use of unconventional fuels for heat production. In this study, samples of waste biomass are analysed as pure feedstock and in mixture with wood shavings and/or inert solid (i.e. sand), in different arrangements and proportion to modify the bed porosity. This approach required the ability to reproduce the combustion phases on representative samples, with an accurate characterization of the instantaneous reaction products. Indeed, the experimental tests are developed on the laboratory scale, but on much larger quantities than the analytical one, to preserve the representativeness of heterogeneous materials, and to better represent the transport phenomena. The results show that the unconventional fuels are well suited for heat production, causing low emissions of incomplete combustion products.

Introduction
Several studies explored technologies for energy recovery from waste biomass, through direct combustion, gasification, roasting, biogas generation and bioethanol production. To these advanced thermochemical processes must be added, including co-combustion of biomass with coal or natural gas, fast pyrolysis, plasma gasification and gasification of supercritical water. In recent years roasting has been widely applied to wood and grass (Uemura et al., 2011; Zhang et al., 2010). Among the most developed technologies, there is certainly the direct combustion (Overend, 2004) and the application of a traditional method for the use of biomass energy (Demirbas, 2004). The biomass combustion process involves both a strong chemical transformation process and a process of heat and mass transfer between the fuel and the air. In addition to fuel, this type of combustion requires an adequate supply of heat and air (Li et al., 2017). However, the equipment (ovens), especially for small-sized applications and to treat materials that are classified as difficult fuels, are erroneously considered to be simple to manage and are often built according to tradition, without rational criteria that take into account the peculiarities of fuels, especially if not conventional. Common limits of all these techniques are represented by the inadequate industrialization and standardization of the plants, mainly linked to problems of fuel homogeneity, which must always be coupled with very energy-intensive pre-treatment systems, to reduce the problems of agglomeration of fuel and corrosion of materials.

Material
Experimental tests are carried out on unconventional waste biomass (Figure 1), which are considered difficult to treat thermally, due to the high moisture content (>> 30%) and heterogeneity of the matrix. Among the tested materials are scraps from the breeding industry (manure, pollen, plumage) and residues of agricultural processing (limbing, mowing and straw).

Figure 1: An image of unconventional fuel (horse manure)

Methods

The experimental tests are carried out in an innovative apparatus, called macro TGA, with a load capacity suitable to reproduce the compositional and morphological variety of the materials. The traditional thermo-gravimetric techniques load samples on the order of mg, instead our configuration allows to load the waste in larger quantities (order of tens of g), so as to minimize the arbitrariness of the sampling and the heterogeneity of the solid matrix. It is possible to reproduce various typical operating conditions of the combustion-gasification-pyrolysis chamber. The apparatus allows to simultaneously measure the sample weight, the feeding of a gaseous stream with modifiable composition (for oxygen, humidity, CO_2 content) and the products of combustion, which can be analysed with various analytical techniques (Electrochemical sensors, GC, FTIR, GC-MS, MS), including continuous particulate monitoring using a laser diffraction sensor. The heating can be imposed on the inlet gaseous stream or through thermal resistances on the reactor wall (Figure 2).

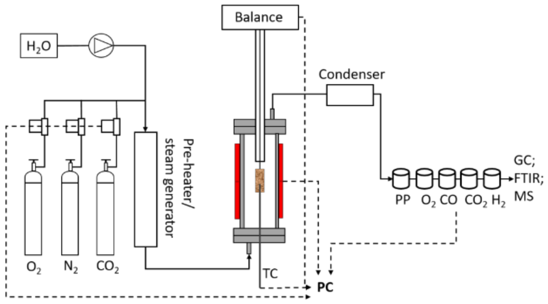

Figure 2: Plant scheme for the characterization and treatment of biomass

Results

In Figure 3, we show an example of the association between the weight loss and thermal degradation profile of the biomass (above) with the trend of gases (CO_2, O_2 and CO - below), detected in the gaseous mixture produced continuously during the material degradation.

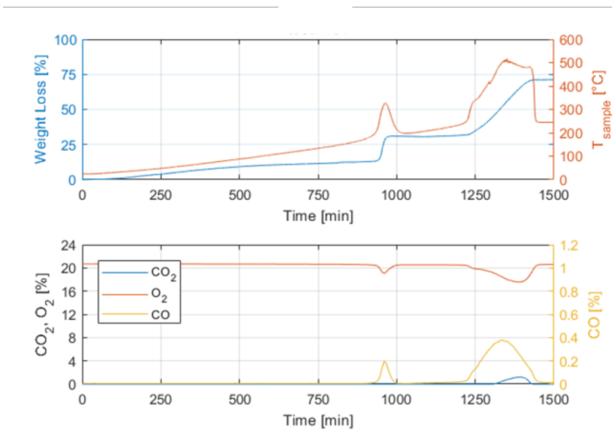

Figure 3: Thermal degradation in waste biomass (horse manure), at 0.2 °C/min, in air

Conclusions

The waste biomasses pose frequent management difficulties. However, it also has great potential to be used as an energy source. Unconventional fuel mixed with shavings and/or sand seems directly suitable for combustion. Indeed the permeability, texture, and thermal properties (conductivity and heat capacity) of the solid fuel are the key factors determining the development of the direct combustion. Understanding these mechanisms is fundamental for a rational design of the combustion furnaces.

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