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Biological degradation of torrefied wood and charcoal

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ARTICLE INFO

Article history:
Received 5 May 2014
Received in revised form
19 August 2014
Accepted 10 October 2014
Available online 30 October 2014

Keywords:
Torrefaction of wood
Charcoal
Storage
Moisture
Decay
Fungal growth

ABSTRACT

Torrefaction is an interesting option to pretreat biomass in order to obtain a fuel with improved handling and combustion characteristics, but there are a number of questions related to the supply chain and especially storage. To investigate the susceptibility of torrefied and charred spruce and birch to biological degradation, two experiments were conducted: a controlled laboratory fungal growth experiment with four different wood utilizing fungi and a preliminary field experiment with uncontrolled conditions. In laboratory, changes in moisture content, carbon and nitrogen contents and mass were measured, and the growth of the fungi was determined visually. Increasing pyrolysis temperature decreased fungal growth, but loss of carbon was noted in all of the samples. Fungal growth increased the moisture contents of samples. In the field experiment dry matter loss and increase of moisture content was noted. Torrefied wood and charcoal seem to not have full resistance towards fungal degradation. This creates additional problems that have to be taken into account when planning the supply chain of the material, as outside storage may not be advisable.

1. Introduction

Pre-treating biomass by torrefaction has provoked much interest in recent years, because the resulting material has improved properties compared to those of the feedstock. In the process, biomass is roasted in a relatively mild temperature range of 200–300 °C, in absence of oxygen and at atmospheric pressure [1,2]. The end product has coal-like characteristics and thus could be efficiently co-combusted in existing coal-fired power plants [2].

An important part of the supply chain of any fuel is the storage. This is also a very challenging part when biomasses are in question, as large quantities are needed for continuous operation. Biomasses have a tendency to absorb moisture and degrade as a result of biological activity. Still, outdoor storage in large piles is a preferred option for e.g. wood chips due to the low costs of this method. Compared to coal, that can be stored outside in large uncovered piles with ease, degradation of untreated wood chips starts quickly, and loss of dry matter, deterioration of quality, and sometimes even spontaneous ignition take place [3,4]. Storing woody biomasses in silos or covered piles increases costs and thus is not a preferred method for large power plants.

Torrefaction changes the properties of biomass from hydrophilic to hydrophobic due to which easy storage has

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http://dx.doi.org/10.1016/j.biombioe.2014.10.009
0961-9534/

been one of the acclaimed benefits of this method [5,6]. Hydrophobic traits appear in the dehydration reactions where the destruction of many hydroxyl groups and formation of unsaturated, non-polar structures take place [2]. As decaying agents require minimum 15–20% moisture content (MC; wet basis, W.B.) [7–9], torrefied wood should be inert to biodegradation. In addition, the heat-induced caramelization process degrades low-molecular carbohydrates, which lose water and become more aromatic [10,11]. Heat-treated wood should therefore also be less suitable for mold fungi that mainly use easily assimilable substances, such as simple sugars, starch, fats, and proteins as a source of nutrition [12]. However, there are several bacteria and fungi that can also modify and decompose dry and seemingly unfavorable materials such as chemically modified wooden structures, lignite, and even hard coal [12–14]. Several micro-organisms have also adapted into living on charred wood from forest fires [12,15] and are potential utilizers of torrefied wood and charcoal in storage. When storing untreated woody material, many white- and brown-rotters can cause severe mass losses [16]. Although molds usually do not significantly affect the properties of wood, they cause health problems for workers and pose a threat for working safety [17].

The objective of this work was to study the ability of different fungi to degrade and utilize pyrolyzed wood (i.e. torrefied wood and charcoal). Based on this, the aim was to draw conclusions on the material's suitability for outdoor storage and on the durability against decay in respect to four different treatment temperatures. Two experiments were carried out: a controlled laboratory fungal growth experiment with four different wood utilizing fungi and favorable conditions, and an uncontrolled field experiment. Dry matter loss and changes in carbon, nitrogen and moisture contents were recorded.

2. Material and methods

2.1. Sample pre-treatment with pyrolysis

One mature spruce tree (*Picea abies* Karst.) and several young birches (*Betula pubescens* Ehrh.) were manually felled in Helsinki, Finland (approx. 60°21′6 N; 25°02′4 E). The stems and thick branches (ø min. 5 cm) were manually cut into blocks of approximately 5 × 5 × 5 cm and dried to an average MC of 6% (dry basis, D.B.) in a cold-air dryer. The size was mandated by the pyrolysis apparatus, an indirectly heated pilot scale reactor managed by Kouvola Region Vocational College's bioenergy project Biosampo. The material was pyrolyzed in 25 kg batches, at 220 °C, 260 °C and 300 °C (torrefaction) and 450 °C (charcoal). The pyrolysis was executed in steps: 110 °C 60 min, 170 °C 60 min and peak temperature with a holding time of 3 h. Long steps were necessary to ensure complete evaporation of water and thorough heat conduction within the blocks. After 3 h heating was switched off and the reactor was left to cool. Treatment at 450 °C required an extra step at 290 °C in order to prevent damage to the reactor. The effect of the long residence time on the extensive charring of the more reactive birch was tested with an additional comparative test run at 300 °C, with half the residence time (30 × 30 × 90 min).

Sample blocks were taken randomly from each temperature batch and split with a knife into smaller pieces. Also 100–200 μg samples of each block were ground for carbon–nitrogen (C/N) analysis performed with VarioMAX (Elementar Analysensysteme GmbH, Germany).

2.2. Laboratory fungal growth experiment

In the laboratory experiment samples split from the original blocks, measuring approximately 1 × 2 cm, were inoculated with four selected fungal species and incubated in an environment excluding outside disturbance factors, such as variation in temperature and humidity. The focus in selection was on fungi that would utilize charred and heat-treated wood and could be found in Finnish environment. The original strains were: *Phanerochaete chrysosporium* Burds. F1767 (FBCC283), *Pycnoporus cinnabarinus* (Jaqc.) P. Karst 331 (FBCC130), *Gloeophyllum sepiarium* (Wulfen) P. Karst PO121 (FBCC 190) and the genus *Trichoderma* spp. (Pers.) (FBCC1529). The strains were obtained from Fungal Biotechnology Culture Collection (FBCC) maintained in the Department of Food and Environmental Sciences, Division of Microbiology, University of Helsinki. *P. chrysosporium* and *P. cinnabarinus* are white rotters, *G. sepiarium* a brown rotter and *Trichoderma* spp. mold fungi. The fungi were grown on Petri dishes with 2% (wt/vol) malt extract agar medium for four weeks (80% RH, 25 °C). New plates with 2% water agar medium were prepared and small plugs of each fungus were inoculated on the dishes. The growth medium, the sample pieces and untreated reference pieces were autoclaved (120 °C, 20 min). Four parallel groups were established and marked I–IV. The moisture contents of the wood pieces (3–4 pieces per plate) were determined prior to the experiment by drying (105 °C, 24 h) and using the equation MC(W.B.) = (M1 − M0)/M1 * 100, where M1 is the wet mass and M0 the oven dry mass. The dishes were sealed with Parafilm M (SPI supplies, USA). The dishes were placed in a climate chamber (WEISS WK11 340, Weiss Klimatechnik GmbH, Germany) at a relative humidity (RH) of 80% and temperature of 25 °C. The growth of the fungi was evaluated by photographing the dishes after 0, 30 and 60 days of incubation. Photographing and measuring the MC required opening the dishes and they were disposed after measurements. Mass loss was measured by weighing the dishes before and after the experiment.

After 30 days (group IV) and after 60 days (groups I, II and III) were weighed and the MC of the sample pieces was determined. The plates were discarded after measurement due to contamination. A 5-step matrix for visual assessment was used to evaluate the advance of fungal growth: 1 – very sparse growth; 2 – sparse growth; 3 – mediate growth; 4 – considerable growth; 5 – abundant growth with discoloration of the medium. If there was no visible growth on the wood samples, but some mycelium on the water–agar medium, the evaluation was 1 in the matrix (very sparse growth), although this growth was most likely sustained by the medium instead of the substrate.