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Characterization of gaseous emissions and ashes from the combustion of furniture waste

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ABSTRACT

Gaseous emissions and ash obtained in the combustion of furniture waste have been studied, with particular emphasis on the emissions of hazardous pollutants, such as PCDD/Fs and dl-PCBs. Two different combustion procedures were carried out, one of them in a conventional residential stove (without an automatic control of combustion air and bad mixing of combustion gases with air), and the other in a laboratory-scale reactor (operating under substoichiometric conditions).

Three different experiments were carried out in the residential stove, in which the gaseous emissions and ashes obtained were analysed. The fuel burnt out in two of the experiments was furniture wood waste and in one of the experiments, the fuel burnt out was briquettes composed of a mixture of furniture wood with 10 wt.% of polyurethane foam. One of the purposes of these experiments was the evaluation of the possible inhibition effect of the higher nitrogen content on the formation of PCDD/Fs. Slight inhibition of the PCDD/F formation was found although, it is noteworthy that the lowest yield of PAHs, volatile and semi-volatile compounds were obtained in the combustion of these briquettes.

In all experiments, the emission factors of polychlorinated dibenzo-*p*-dioxins and dibenzofurans and dioxin-like polychlorinated biphenyls (PCDD/Fs and dl-PCBs) were between 29 and 74 ng WHO-TEQ/kg sample burnt, lower than that obtained by other authors in the burning of pine needles and cones.

PCDD/Fs and dl-PCBs emissions from furniture wood waste combustion were also analysed in the laboratory scale reactor at 850 °C and the results were compared with the values obtained from the combustion of solid wood (untreated wood). The total equivalent toxicity obtained was 21.1 ng WHO-TEQ/kg sample for combustion of furniture wood waste, which is low in comparison with those obtained for other waste combustion in similar conditions.

In the laboratory scale reactor, PCDFs were the dominant compounds in the profiles of PCDD/Fs, by contrast, in the combustion in the residential stove, the majority compounds were PCDDs, due to the different operation conditions.

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1. Introduction

The European Directive on solid waste management (Directive 2008/98/EC) proposed a hierarchic waste policy, which consists of: (1) prevention; (2) re-use; (3) recycling; (4) other recovery, e.g. energy recovery; and (5) disposal.

Panelboard manufacture, used for animal bedding, or used as bulking agent for composting are different ways of recycling wood. Nevertheless, it must be taken into consideration that the additives present in furniture wood, such as metals, chlorine, pentachlorophenol, etc. could restrict the recycling. For instance, the German Ordinance on the Management of Waste Wood (BMU,

2002) regulates the limits of some elements/compounds for the wood waste used in the manufacture of panelboard; but treated wood usually exceeds these limits. Therefore, combustion for energy recovery can be an appropriate management method for furniture wood waste, avoiding its disposal in landfills.

Lignocellulosic wastes, such as wood, are being widely used as a renewable energy source due to the significant reduction in the emission of acid and greenhouse gases, as well as improved management of natural resources. Therefore, energy recovery is a possible way to manage with these wood wastes, because its use improves the management of environmental resources and wastes.

The additives contained in furniture wood waste hinder their recycling and re-use, so furniture wood combustion shows some disadvantages compared with natural wood combustion, such as NO_x increase, higher heavy metal emissions and increase of

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PCDD/Fs, dioxin-like compounds and other organic compounds (Lavric et al., 2004).

Furniture wood contains nitrogenated adhesives, such as urea formaldehyde, melamine formaldehyde, melamine-urea-formaldehyde resins, polymer isocyanates (Pizzi and Mittal, 2011), flame retardants, such as ammonium salts (Di Blasi et al., 2008; Kozłowski and Władysław-Przybylak, 2001), and amino resins modified with phosphoric acid (Gao et al., 2003). Nitrogen content produces NO_x, NH₃ and HCN predominantly during biomass combustion (Stubenberger et al., 2008). NO_x emissions can come from three routes of formation during combustion: thermal NO_x is produced at temperatures higher than 1100 °C from atmospheric nitrogen, the prompt NO_x is formed from the radical CH as an intermediate at the flame front and the fuel- NO_x is formed from nitrogen of the fuel (Werther et al., 2000). Nevertheless, at temperatures lower than 1000 °C, NO_x is expected to be produced mainly from the nitrogen of the fuel (Roy and Corscadden, 2012).

Not only heavy metal emissions (particles, volatile halides, etc.) are harmful, but also the pollutant retention in the ash, which restricts its use for disposal in agricultural soil (Oberberger et al., 1997).

On the other hand, it must be noted that incomplete combustions cause environmental concerns, mainly due to particulate matter (PM), polycyclic aromatic hydrocarbons (PAHs) and carbon monoxide (CO) emissions. For instance, Bari et al. (2011) reported that the smoke formed during the combustion of wood in residential heating contains small particles, and thus represents a particular health risk because of its respirability and content of polycyclic aromatic hydrocarbons (PAHs).

Some of the most harmful emissions to human health are the polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) and dioxin-like polychlorinated biphenyls (PCBs). Their formation is probably via two main pathways (Salthammer et al., 1995): (i) via precursor compounds such as pentachlorophenol, which has been widely used as a preservative in wood, and (ii) the novo mechanism, which consists of the combination of carbon, oxygen and chlorine at low temperatures (between 200 and 400 °C) and catalyzed by a metal, mainly Cu.

The presence of chlorine in wood increases the PCDD/F formation, due to either salt-laden wood or organochlorinated additives, such as pentachlorophenol (Altwickler et al., 1990; Preto et al., 2005; Thuß et al., 1997; Yasuhara et al., 2003).

Some typical preservatives of wood show Cu in their composition, such as copper chromium arsenate, copper chrome boron, alkaline copper quaternary, copper boron azole, and copper naphthenate. It has been demonstrated that the presence of Cu increases the formation of PCDD/F (Tame et al., 2003b, 2005). The combination of chlorine and copper in wood preservatives shows a higher formation of PCDD/F; for instance, the tebuconazole pesticide, which is a chlorinated compound, present in copper boron azole preservative provides chlorinated precursors for PCDD/F formation and Cu as a catalyst (Tame et al., 2005).

Besides the catalytic effect of copper, Qian et al. (2005) and Pandelova et al. (2007) found that other metal oxides also promote formation of PCDD/Fs. For instance, TiO₂, which is present in furniture wood due to the paints, also shows a promotion effect on PCDD/F formation, although, the strongest catalytic effect was observed with CuO.

Combustion conditions have also been found to be an important factor in the formation and distribution of PCDD/Fs. Salthammer et al. (1995) observed that the type of combustion chamber has a significant influence on the distribution of congeners. A literature survey concludes that the conditions to minimize PCDD/F formation are maximization of combustion temperature, gas residence time and turbulence of the gases, and an excess of oxygen of 3–6% (v/v) (McKay, 2002).

On the other hand, the PCDD/F inhibition due to nitrogen content has been found in studies of wood combustion. For instance, Skodras et al. (2002) studied the combustion and the co-combustion of natural wood, Medium-Density Fibreboard (MDF) (with nitrogen additives), power poles (with high metal content) and lignite and they observed that the lowest PCDD/Fs emissions were during combustion of fuel containing MDF. Bhargava et al. (2002) also studied the PCDD/F emissions from combustions of chipboard and MDF (with nitrogen additives) in a cone calorimeter. They found toxic equivalencies of 20.5 and 15.4 ng TEQ/kg sample for chipboard and MDF, respectively.

Gaseous NH₃ has been also found as an effective inhibitor of PCDD/F formation (Hajizadeh et al., 2012; Ruokojärvi et al., 2004, 1998). Furthermore, the first stage of combustion is a pyrolysis process, in which the ammonia formation is high if the nitrogen content of the fuel is significant (Moreno and Font, 2015).

Therefore, the objective of the present work is the study of the toxic emissions and the toxic content of the ashes from the combustion of furniture waste. Experiments were carried out in a residential stove (without an automatic control of the combustion air and bad mixing of the combustion gases with air) and with a laboratory scale reactor (operating under substoichiometric conditions with airflow and temperature control but a good mixing of volatiles evolved) to observe the formation of pollutants under these conditions.

Three different experiments were carried out in the residential stove. In two of them, the fuel used was furniture wood waste and the other experiment was carried out with briquettes of furniture wood waste with the addition of polyurethane foam (material with higher N content) to test the possible inhibition of PCDD/F formation by the ammonia formation during the pyrolysis stage. A previous work concluded that briquettes of furniture wood with an addition of 10 wt.% of polyurethane foam show good quality (durability and density of the briquettes) (Moreno et al., 2016). For this reason, this combustion experiment was carried out with briquettes of furniture wood with 10 wt% of polyurethane foam.

PCDD/Fs and dioxin-like PCBs were also analysed in a laboratory reactor under fuel rich conditions with furniture wood waste (treated wood) and solid wood (untreated wood), in order to compare the effect of the global effect of the additives present in furniture wood waste (higher chlorine, metal and nitrogen content). In this reactor, the combustion conditions are perfectly controlled, therefore the differences in the PCDD/F and dl-PCB formation can only be possible due to the different composition of the wood studied. These set-ups were carried out under substoichiometric conditions to promote the formation of products of incomplete combustion.

2. Experimental section

2.1. Characteristics of the materials

Furniture wood waste and polyurethane foam were collected from a Municipal Solid Waste Treatment Plant and solid wood (untreated wood) from a furniture factory. Prior to the experimental runs, the woody samples were dried and milled to a size less than 0.2 mm to obtain representative samples for the further characterization of the samples and for the experimental runs in the laboratory-scale reactor.

The characterization of the materials and the methods used were presented in previous works (Garrido and Font, 2015; Moreno and Font, 2015). For comparison, the results are also shown in Table 1. Note that the nitrogen content of the solid wood is below the limit of detection. For some elements, the standard

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