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Effect of wood pre-treatment on operating conditions and PM emissions during combustion at laboratory scale

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Abstract

This work aims to study the influence of the nature of biomass fuel and its pre-treatment on both emission factors of gaseous and particulate pollutants generated by new domestic heat generation in real use conditions. Indeed, these last years, domestic wood heating manufacturers have highly optimised combustion conditions, thanks to new technologies development, to respect the new European legislation proposed in 2022. In order to increase the environmental performance of these installations, some properties of the biomass fuel used (type, size, thermal reactivity, chemical composition, moisture rate, ash content …) were linked to the emission factors of gaseous and particulate pollutants generated by combustion.

We focus on beech pretreatment by washing process at laboratory scale. Both untreated and washed woods were combusted in a pellet stove in order to compare the environmental impact of the wood washing process on gaseous and particulate emissions.

Keywords: Wood; Combustion; Washing pretreatment; Particulate emissions; Gaseous emissions; Minerals

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1. Introduction

Wood pellets became an important fuel in domestic heat generation, since the coasts of fossil fuels are rising and the emissions are nearly CO_2 neutral. In contrast to other wood logs, the use of pellets is easy and automatic feeding is possible. Furthermore, the pelletisation increases the energy density. On one hand, wood pellets are a convenient choice for domestic fuel because of their simplicity of implementation and their low cost. But on the other hand, wood pellets combustion is a source of fine Particle Matter ($PM_{2.5}$) (Win et al., 2012). In the last decade, numerous studies were devoted to the evaluation of emission factors for gaseous compounds or $PM_{2.5}$ from residential wood combustion appliances. Most of them attempted to compare pollutant emissions as a function of both the nature of the wood and/or technologies of the domestic heating appliances (Boman et al., 2011). Investigations on both influences of the wood preparation and pre-treatment on PM emissions are scarce.

An aerosol is composed of mineral and organic particles. The mineral part mainly consists in metallic trace elements, sulphates, nitrates, ammonium and salts (KCl, K_2SO_4, $CaCO_3$, CaO…) (Schmidl et al., 2008). The organic part is itself composed of elemental and organic carbon. By washing wood, we expected to extract minerals and thus reduce the mineral part in wood combustion smoke.

2. Experiments

2.1 Washing procedure

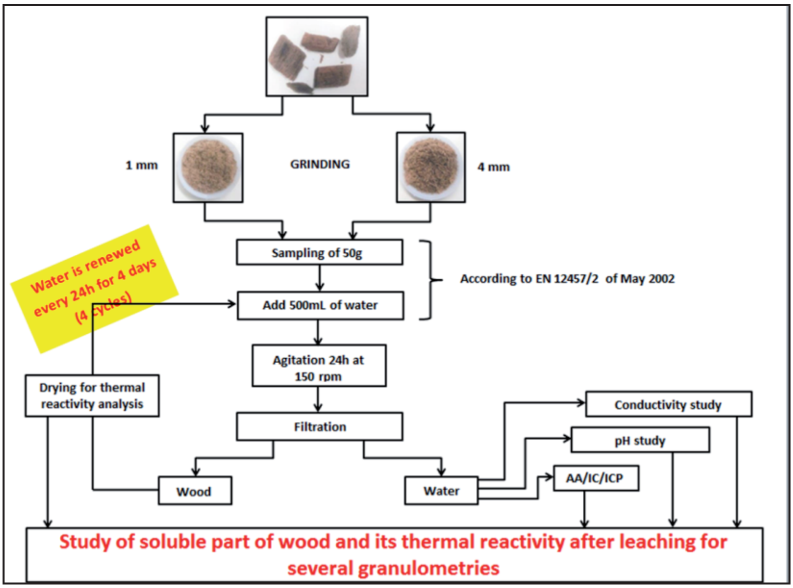

Fig. 1. Experimental washing process

Pre-treatment of wood fuel, such as beech sawdust was carried out at laboratory scale following the standard lixiviation protocol EN 12457/2 of May 2002. The experimental washing process is schematized in Figure 1. Each 24 hours washing represents one cycle. Demineralised water is substituted every 24h for a total time of 96h. Wood washed for 24, 48, 72 and 96 hours is respectively named beech washed C1, C2, C3 and C4.

The conductivity was recorded for each washing waters in real time. Each washing water was analyzed by ICP to determine the percentage of removal of several minerals. After each cycle, a sample of wood was dried to be analyzed by thermogravimetry to study their thermal reactivity.

2.2 Characterisation of biomasses

Beech chips were purchased from Agrivalor (Hirsingue, France). Both untreated and washed samples were characterized for ash contents and Low Heating Value (LHV). LHV and ash content values of untreated beech were found to be of 18 MJ. kg^{-1} and 0.36%, respectively. Washing procedure slightly decreases LHV by 6% whatever the number of the cycles. Ash content was affected by the washing cycle by a 22% reduction after 96h.

2.3 Combustion experiments

Combustions tests at laboratory scale were performed in a pellet stove supplied by Hoben (Model H5 Signature Color Steel). The nominal heat out-put of the pellet stove is 6.3 kW. Combustion tests were realized for a power of 100% and a modulation of air of 50%.

2.4 Gaseous emissions

Emissions were measured in the chimney during experiments at laboratory scale on the pellet stove. O_2, CO, CO_2 were analyzed by specific analyzers Hartmann & Braun and THC were recorded by a flame ionization detector Cosma. According to EN 13240/A2 standard, concentrations expressed in mg. Nm^{-3} were referred to 13% of O_2 in the exhaust to insure comparison for both experiments.

2.5 Particulate matter

An Electrical Low Pressure Impactor (ELPI) manufactured by DEKATI Ltd. (Tampere, Finland) was used to collect particles from 7 nm to 10 µm into 12 size fractions. ELPI device is well described in Marjamäki et al. (Marjamäki et al., 2000). Particle number and concentrations calculated accounts for 1 g. cm^{-3} of density value. The total mass fraction of Total Suspended Particles (TSP) has been measured by gravimetry according to DIN Certco certification rules (DIN CERTCO, DIN EN 13240, 2011).

3. Results and discussion

3.1 Conductivity study

Conductivity of the leaching solution for each cycle was recorded every five seconds (Fig. 2). This graph shows that the main part of elements is extracted during the first cycle. Whatever the cycle, a balance between wood and water is established after approximately 5-6 hours of washing meaning that a 24 hours cycle can be reduced to only a 6 hours cycle for large scale washing.

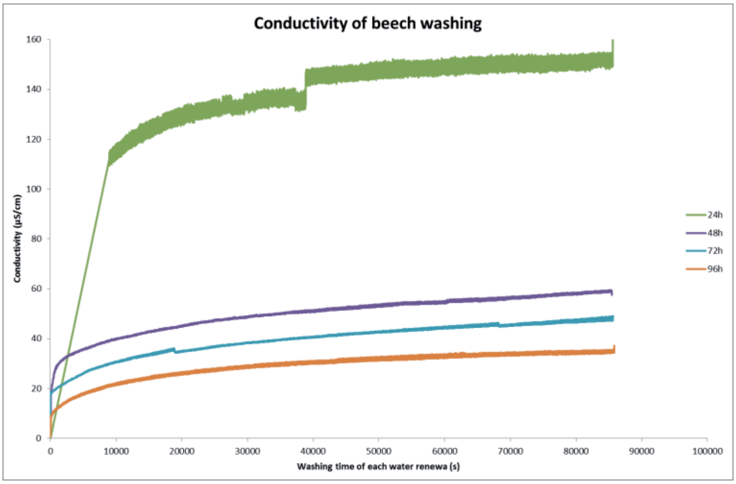

Fig. 2. Conductivity of each washing cycles

3.2 Minerals concentrations

As conductivity decreases after each washing cycle, a variation of minerals concentrations was also expected. By analyzing both untreated wood and all washing waters, the percentage of removal for several elements could be determined (Table 1). The washing process shows that potassium and sulphur are totally extracted from washed wood. Moreover, magnesium and phosphorous have been well removed too, close to 70%. However, some elements, such as aluminium, calcium and iron could not be extracted from beech wood. Concerning anions, results are still under investigation.

Table 1. Percentage of removal for several elements

Elements	Untreated beech ($mg.kg^{-1}$)	All washing waters ($mg.kg^{-1}$)	% of removal
K	1285	1335	~ 100
S	38.3	41.4	~ 100
Mg	64.3	47.3	74
P	31.3	22.4	71
Zn	0.084	0.048	57
Al	14.8	0.55	4
Ca	2462	95.1	4
Fe	17	0.51	3

3.3 Thermal reactivity study

Thermal properties of beech wood were studied by thermogravimetric analysis under air with a temperature ramp from 20°C to 700°C at 5°C min^{-1}. Thermograms of both untreated and washed wood are quite similar. Only slight modifications of maximal rate values are observed. Two important steps are pointed out according to literature (Orfão et al., 1999): the devolatilisation of sugar polymers such as hemicellulose and cellulose at 320°C that leads to a char formation and the devolatilisation of lignin polymer and the char oxidation at 450°C.

By plotting maximal rate of cellulose devolatilisation versus washing time of each cycle, a linear curve is obtained (Figure 3). The maximal rate of cellulose devolatilisation slightly increases with the number of washing cycles whatever the particle size of the beech wood (1 or 4 mm). On the contrary, by representing maximal rate of char oxidation versus washing time, a decrease for both 1 and 4 mm granulometries is observed (Figure 3). Considering initial and final states, the two granulometries finally give the same result. If the reactivity of the char continues to decrease with the number of washing cycle in the case of 4 mm size, its reactivity does not change after one cycle for the 1 mm size. The exchange surface could explain this phenomenon. Some minerals such as potassium should be extracted faster for the smallest grinded sample. Some minerals, such as potassium, are known to be catalyst of carbon oxidation, particularly in this temperature range (Bouraoui et al., 2016). As potassium is totally removed from washed wood, it could decrease the char oxidation rate.

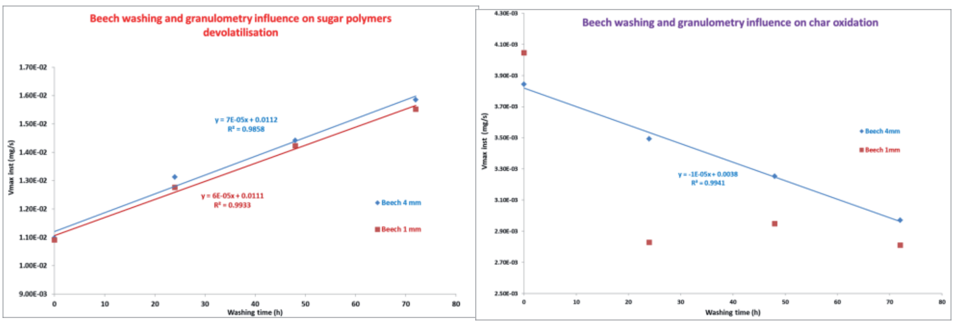

Fig. 3. Thermal properties of beech wood: Cellulose devolatilisation (left) and char oxidation (right)

3.4 Gaseous and particulate emissions from beech combustion

Gaseous and particulate emissions from both untreated and washed wood beech measured in the exhaust are listed in the Table 2. A slight decrease in carbon monoxide emissions is observed and by a factor 3 and 2 for THC and TSP respectively. $PM_{2.5}$ number concentration is also reduced by 10% using washed wood. PM size distribution shows that two times more ultrafine particles ($PM_{0.1}$) are emitted.

Table 2. Combustion results

Sample	CO_2 (%)	CO ($mg.Nm^{-3}$)*	THC ($mg.Nm^{-3}$)*	TSP ($mg.Nm^{-3}$)*	$PM_{2.5}$ ($p.cm^{-3}$)	$PM_{0.1}$ (%)	$PM_{0.1-1}$ (%)	$PM_{1-2.5}$ (%)
Untreated beech	4.3	740	12.9	88	7.7E7	16.3	83.6	0.1
Beech C4	3.6	490	4.5	43	7.0E7	31.4	68.5	0.1

* referred to 13% O_2

4. Conclusions

Wood pre-treatment slightly modified fuels properties. Remove minerals from wood decreases ash content and LHV. Further explorations are necessary to understand the variation of heating values. Conductivity decreases after each cycle of washing and minerals are well extracted from wood. Some of them are totally removed (K and S). Finally, first combustion tests of washed wood pellets show a significant environmental impact on emissions with significant decreases in gaseous and particulate matter. Same experiments on different types of wood are in progress. Chemical compositions (minerals, wood tracers such as sugars) of TSP and ash composition will provide information for the further determination of demineralisation kinetics.

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References

Boman C., Pettersson E., Westerholm R., Boström D., Nordin A. (2011). Stove Performance and Emission Characteristics in Residential Wood Log and Pellet Combustion, Part 1: Pellet Stoves. Energy Fuels 25, 307–314.

Bouraoui Z., Dupont C., Jeguirim M., Limousy L., Gadiou R. (2016). CO2 gasification of woody biomass chars: The influence of K and Si on char reactivity. Comptes Rendus Chim. 19, 457–465.

DIN CERTCO, DIN EN 13240 (2011). Certification Scheme - Room Heaters for solid fuels with low-pollution combustion (Berlin).

Marjamäki M., Keskinen J., Chen D.-R., Pui D.Y.H. (2000). PERFORMANCE EVALUATION OF THE ELECTRICAL LOW-PRESSURE IMPACTOR (ELPI). J. Aerosol Sci. 31, 249–261.

Orfão J.J.M., Antunes F.J.A., Figueiredo J.L. (1999). Pyrolysis kinetics of lignocellulosic materials—three independent reactions model. Fuel 78, 349–358.

Schmidl C., Bauer H., Dattler A., Hitzenberger R., Weissenboeck G., Marr I.L., Puxbaum H. (2008). Chemical characterisation of particle emissions from burning leaves. Atmos. Environ. 42, 9070–9079.

Win K.M., Persson T., Bales C. (2012). Particles and gaseous emissions from realistic operation of residential wood pellet heating systems. Atmos. Environ. 59, 320–327.