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Research paper

Impact of ignition technique on total emissions of a firewood stove

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ABSTRACT

A comparison of the effects of traditional stove ignition with paper under the wood versus the Top-Down ignition of a wood crib is made, comparing the gaseous and particulate emissions. Top-Down ignition reduced the unburnt gas emissions by a factor of 2. The Total Suspended Particle (TSP) emission was reduced by about 1/3, while Organic Carbon (OC) was reduced by 73% relative to traditional under-fire ignition. Never the less the Elemental Carbon (EC) doubled in Top-Down ignition. The particle formation mechanism is also different with primary emissions being nanoparticles (20 nm - 50 nm) which agglomerated as they passed along the flue duct. The TSP were generally composed of CHO while the smaller size range $< PM_1$ and especially the $PM_{0.1}$ contained other elements.

1. Introduction

Most developed countries depend on fuel, which leads them to increasingly use and improve renewable energies. Saidur et al. [1] demonstrated that domestic wood heating, which is composed of boilers (central heating, hot water) and biomass room heating appliances (room heating, hot air), is the first renewable energy and is the one that is promoted. Moreover, Kalt and Kranzl [2] showed that domestic wood heating is one of the cheapest energies, especially for logs. In this context, the sales of wood domestic appliances have considerably increased in all Europe [3]. In Europe, the residential sector (except for pellets) is the main share of wood energy with 27% of the total use [4]. Then, in this study, the performance of a firewood stove was focused on. Many scientific papers describe this energy as an important source of particles emissions [5–8] particularly during winter [9]. Particles in the ambient air represent an important risk for health because of their size, their surface and their composition [10–14]. Moreover, the composition in Elemental Carbon (EC) and Organic Carbon (OC) of particles induces a modification of the radiative balance of the earth and also changes the composition of the clouds [15–17]. The particles in the atmosphere from wood fuel combustion are not only due to the direct particulate emission but also to a physical and chemical condensation process that produces additional particles from volatile compounds in the flue gases [18]. The Secondary Organic Aerosols (SOA) are an important fraction of the particles in the ambient air [8]. Therefore, the Volatile Organic Compounds (VOC) and the Total Suspended Particles (TSP) need to be measured simultaneously [19]. Even if some secondary emission abatement systems do exist and are suitable for firewood stoves [20,21], only few installations are fitted. Then the emissions in firewood stoves must first be reduced by the user. Many primary measures were developed, (secondary air, insulation of the combustion room …) and led to cleaner combustion. Many parameters independent of the user impact the emissions and the thermal efficiency (i.e. chimney system and weather conditions). One of the parameters that most impacts on the emissions is the operating practice [20,22] like fuel characteristics [23], combustion air supply settings [24] or the ignition technique. These improvements of firewood stoves are sustained by the evolution of standards and labels [21]. Nevertheless, the fuel feed and the ignition of firewood stoves remain highly emissive [25]. Indeed, during the ignition phase, the furnace and hearth are cold and lead to high emissions of unburned gas and particles. In order to solve this issue, the Top-Down ignition was recommended in Switzerland. The Top-Down offers an advantage to induce a more progressive ignition. Indeed, as the flame is on the top, the radiation will be more gradual and then the emissions of pyrolysis gases will also be progressive. On the contrary, with a Traditional Ignition system, the whole fuel is directly heated by the combustion. Miljevic et al. [26] demonstrated that this kind of ignition reduced the Total Suspended Particles (TSP) emissions contrary to Vicente et al. [27].

Several different pollutants were followed, namely CO, NO, SO_2, Total Volatile Organic Compounds (VOC), CH_4, Total Suspended Particles (TSP), Total Carbon (TC), Elemental Carbon (EC) and Organic Carbon (OC). By measuring the CH_4 emissions separately in addition to the TVOC measurement, it allowed the CH_4/TVOC ratio to be

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measured. Moreover, so as to obtain a better understanding of the mechanisms of formation of the particles, two microscopes were used.

In order to evaluate the impact of both ignitions modes on a real use of the studied stove, a simulation was also developed.

2. Materials and methods

2.1. Stove, combustible and experimental procedures

The WABI (D2I INVICTA, DONCHERY, FRANCE) firewood stove that was designed, built and purchased in 2012 with a nominal thermal heat output of 6 kW was used. The combustion chamber was fitted with primary and secondary air supplies and was insulated with vermiculite. The fuel was split beech (*Fagus sylvatica*) logs of 12 cm of diameter from a 40-year-old beech. The logs were chosen without any knots and bark. They were air-seasoned in greenhouses, and their moisture content was stabilized in a regulated enclosed chamber. Then, the water mass fraction was 0.12 (following the standard EN 14774). The wet base Net Calorific Value (NCV_{wb}), measured following the standard EN 14918, was 16.7 MJ kg^{-1}. The ash mass fraction of the dried material was measured following the standard EN 14775 at 823.15 K and 1088.15 K. The results are: 2.7 g kg^{-1} at 823.15 K; 1.4 g kg-1 at 1088.15 K. The elemental composition of the logs was also measured. In order to obtain a representative result, a complete log was ground up. The sawdust was then mixed, and three samples of 1 g each were analysed. The results were equivalent for each of the three analyses, and are: 495 g kg^{-1} of C; 59 g kg^{-1} of H; 438 g kg^{-1} of O; < 3 g kg^{-1} of N; 108 mg kg^{-1} of S; 64 mg kg^{-1} of Cl.

Two kinds of ignition modes were studied: Top-Down ignition and Traditional ignition (Fig. 1). In both cases, only two sheets of a classic newspaper were used to ignite so as to be close to real conditions. The newspaper used was a paper of 52 g m^{-2}, from thermomechanical pulp (made out of 100% chipped conifer). There was only black lead-free ink on this newspaper. Three tests were realised for each configuration. The combustion platform conforms to the EN 13229 and the Pr EN 16510. The fuel was weighed in order to obtain a comparable mass and improve the repeatability. The description of the loads of woods is presented in Table 1. The air valves for combustion air supply were totally open and the combustion was held with a normalized draft (EN 13229; average for every test: 12 Pa; variation: 2 Pa max during a test). In order to evaluate only the ignition period of the stove, the sampling period began at the closing of the fire door and was stopped when the flames disappeared. Normally a standard user would add logs when once flames disappear to keep the fire burning.

2.2. Sampling and analysis

2.2.1. Physical and gaseous measurement

During each test, many samplings were realised. The gaseous composition of the smoke was studied thanks to a gas analyser PG 350 (HORIBA, KYOTO, JAPAN) which uses different analysis methods:

Fig. 1. Top-Down and Traditional ignition.

Table 1
Detailed mass for each load.

Test	Layer 1 (g)[a]	Layer 2 (g)[a]	Layer 3 (g)[a]	Layer 4 (g)[a]	Layer 5 (g)[a]	Layer 6 (g)[a]	Layer 7 (g)[a]	Total (g)
Top-Down 1	418.8	348.7	117.8	116.8	97.7	82.5	57.2	**1239.5**
Top-Down 2	399.8	335.5	147.1	109.7	92.2	77.2	68.7	**1230.2**
Top-Down 3	524.1	246.2	156.5	128	96.2	49.7	33.1	**1233.8**

	Large wood (g)[b]	Medium wood (g)[c]	Kindling wood (g)[d]	Total (g)
Traditional 1	777.4	123.5	258	**1158.9**
Traditional 2	710.7	240.5	272	**1223.2**
Traditional 3	633.6	284.7	316.6	**1234.9**

[a] The layers match the mass of wood at each level from the bot (1) to the top (7) of the load. Each layer is composed by two firewood pieces.
[b] Large wood matches the mass of a group of logs which have a maximal diameter of 4 cm.
[c] Medium wood matches the mass of a group of logs which have a maximal diameter of 2 cm.
[d] Kindling wood matches the mass of a group of logs which have a maximal diameter of 1 cm.

chemiluminescence detectors (NO); Nondispersive infrared sensor (SO_2, CO, CO_2); paramagnetic detector (O_2). The Total Volatile Organic Compounds (TVOC) were measured with a Flame Ionization Detector (FID) Graphite 52M (ENVIRONNEMENT SA, POISSY, FRANCE). A balance with a resolution of 50 g allowed the evolution of the mass of the stove to be followed. The ambient and the flue gas temperatures (at the sampling point, according to EN 13229) were also measured with K-type thermocouples.

2.2.2. Particulate matter sampling and analysis

The Total Suspended Particles (TSP) were out-stack sampled during the entire period thanks to an isokinetic probe at 283 cm^3 s^{-1} STP on a quartz filter heated at 160 °C (STP in this study: 0 °C, 101325 Pa). Before and after the sampling, the quartz filter was conditioned according to the Pr EN 16510 (4 h in a heat chambers at 180 °C, 4 h in a desiccator, weight of m_0, sampling, 4 h in a heat chambers at 180 °C, 4 h in a desiccator, weight of m_1). For the particles size determination concentration, an Electric Low Pressure Impactor (ELPI) heated at 160 °C was used (DEKATI, KANGASALA, FINLAND). The emissions of Total Carbon (TC), Organic Carbon (OC) and Elemental Carbon (EC) were also measured with a thermal-optical analyser (SUNSET LABORATORY, TIGARD, USA). The sampling was realized at 160 °C on a quartz filter for 100 min, but with a lower flow than the TSP sampling (167 cm^3 s^{-1}). The analysis protocol is described deeply by Brandelet et al. [28].

2.2.3. Microscopy for imagery

In order to improve the physical knowledge of the particles, a Field Emission Gun Scanning Electron Microscope (FEG SEM) was used (ZEISS, OBERKOCHEN, GERMANY). The filter was in polycarbonate with a porosity of 200 nm. The sampling characteristics were: 16.7 cm^3 s^{-1} STP for 25 s at 443.15 K. A secondary electron detector (in lens) was used to obtain high resolution pictures after platinum coating of the filter.

2.2.4. X-ray micro-analysis (EDS)

Many micro-analyzes were performed on the same filter as the one observed with high resolution FEG. Automated detection and qualitative X-ray micro-analysis (EDS elementary analysis) of the particles were performed with INCA-Feature module (OXFORD INSTRUMENTS, ABINGDON, UK)). The detection of particles was performed from backscattered electron emission by particles (BSD) submitted to 20 kV of acceleration beam voltage in High Vacuum (HV) mode (platinum