IMPACT OF WOOD COMBUSTION IN AN OPEN FIREPLACE ON INDOOR RESIDENTIAL AIR QUALITY: RESPIRABLE FRACTION

A. Castro[1*], A.I. Calvo[1], C. Blanco[1], C. Alves[2], E. Coz[3], M. Duarte[2], E. Vicente[2], F. Amato[4], X. Querol[4] and R. Fraile[1]

[1]Department of Physics, IMARENAB University of León, 24071 León, Spain

[2]Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning, University of Aveiro, Aveiro 3810-193, Portugal

[3]Centre for Energy, Environment and Technology Research (CIEMAT), Department of the Environment, 28040 Madrid, Spain

[4]Institute of Environmental Assessment and Water Research, Spanish Research Council (IDAEA-CSIC), 08034 Barcelona, Spain

* acasi@unileon.es

Introduction

In Spain, as in many other European countries, mainly in rural areas, open fireplaces are still present. Important quantities of wood are combusted in these domestic devices every year. Some studies have pointed out that wood-burning fireplaces are potential sources of indoor air pollutants, mainly fine particles. There are several factors that can have an important influence on pollutant emissions, such as the stove design, operating conditions, combustion conditions (e.g. amount of excess air) and the species of wood, as well as their characteristics. The present study aims to characterize aerosol size distributions and chemical composition of particles emitted during the combustion of logs of a common Southern and mid-European wood (*Quercus pyrenaica* –oak–) using a traditional Spanish brick open fireplace operated manually.

Methodology

MATERIAL

- Optical particle counter (PCASP-X): particles with sizes between 0.1-10 µm (Fig 1).
- Gent PM_{10} stacked filter unit sampler using quartz filters for later chemical analyses. In two combustion experiments, polycarbonate filters (0.2 µm pore size) were used for field emission scanning electron microscopy (FE-SEM).
- HERTER meter: CO and CO_2 concentrations.

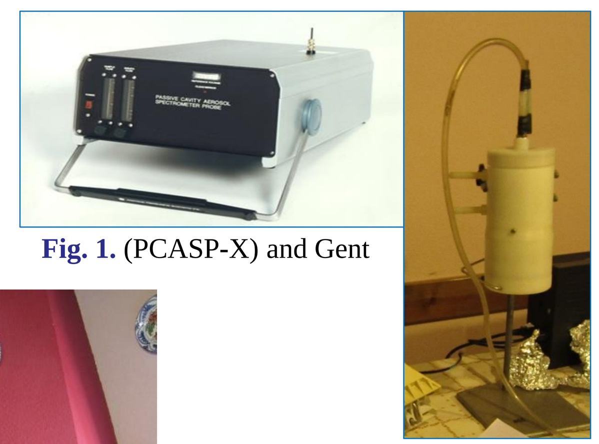

Fig. 1. (PCASP-X) and Gent

EXPERIMENTAL INSTALLATION

A total of 10 combustion experiments were performed in a rural area (Fig. 2). During each experiment, the fireplace (Fig 3) was fed with oak logs four times (F1, F2, F3, F4) (see Fig. 4). This methodology tried to reproduce the common procedure carried out in the houses. In the startup phase (F1), 1.5 kg of oak chips, 400 g of branches and two sheets of newspaper were used. For the other three refueling processes, a total of between 11.5 and 12.7 kg of oak were added. The duration of each combustion experiment was about 4-5 hours. On average, each phase lasted 10, 60, 60 and 130 min, respectively.

Fig. 2. Location of Báscones de Valdivia (Palencia, Spain), with a population of 20 inhabitants according to INE, 2013. Coordinates 42° 45′ 57″ N, 4° 11′ 5″ W, and 912 m above sea level.

Fig. 3. Open fireplace with a combustion chamber volume of 0.09 m^3, corresponding to 0.35 m height, with a trapezoidal base of 0.52, and 0.63 m width and 0.45 m depth. The room volume was 41 m^3

Fig. 4. Oak logs for the refueling process F2

Results and Conclusions

Table 1. Analytical results with the characteristics of oak logs. DRY and AR stand for dry basis and as received, respectively. Gross Calorific Value at constant volume (HCV)v, Low Calorific Value at constant volume (LCV)v and Low Calorific Value at constant pressure (LCV)p were also included.

	DRY	AR	STANDARD TEST METHOD
Total moisture (%)		16.5	ASTM 3302
Volatiles (%)	80.6	67.3	UNE 32019
Ash (815 ºC) (%)	1.88	1.57	UNE 320004
Carbon (%)	49.2	41.0	ASTM 5373
Hydrogen (%)	5.79	6.67	ASTM 5373
Nitrogen (%)	0.10	0.08	ASTM 5373
Sulfur (%)	0.13	0.11	ASTM 4239
(HCV)v (kcal/kg)	4599	3839	UNE 32006
(LCV)v (kcal/kg)	4296	3495	UNE 32006
(LCV)p (kcal/kg)	4278	3474	UNE 32006

Table 2. Total Number of Particles, Total Surface, Total Volume, Count Median Diameter (CMD), Surface Mean Diameter (SMD), Volume Mean Diameter (VMD) and Geometric Standard Deviation (σ_g) of the number, surface and volume distributions for sequential combustion phases (F1, F2, F3, F4), background (BG) and cleaning process of the ashes and embers (CL) for a refraction index estimated from the aerosol composition of 1.577-0.003i.

	NUMBER SIZE DISTRIBUTION			SURFACE SIZE DISTRIBUTION			VOLUME SIZE DISTRIBUTION		
CODE	N_T (cm^{-3})	CMD (µm)	σ_g	S_T ($\mu m^2 cm^{-3}$)	SMD (µm)	σ_g	V_T ($\mu m^3 cm^{-3}$)	VMD (µm)	σ_g
F1	1800 ± 1200	0.15 ± 0.02	1.49 ± 0.04	400 ± 300	1.3 ± 1.2	5.5 ± 1.1	190 ± 120	9 ± 3	2.6 ± 0.5
F2	1800 ± 1000	0.147 ± 0.017	1.47 ± 0.07	400 ± 300	1.4 ± 1.5	5.6 ± 1.6	300 ± 400	9 ± 3	2.7 ± 0.8
F3	800 ± 500	0.128 ± 0.005	1.41 ± 0.05	100 ± 50	1.4 ± 0.8	6.7 ± 0.8	90 ± 40	10.8 ± 1.5	2.3 ± 0.4
F4	400 ± 200	0.129 ± 0.007	1.45 ± 0.11	70 ± 30	2.4 ± 1.2	6.4 ± 1.4	70 ± 40	11.4 ± 1.4	2.1 ± 0.3
BG	40 ± 20	0.128 ± 0.004	1.55 ± 0.04	30 ± 30	5.2 ± 3.0	4.0 ± 1.1	60 ± 70	11 ± 4	1.9 ± 0.3
CL	500 ± 600	0.135 ± 0.001	1.6 ± 0.3	120 ± 80	5.4 ± 5	4.7 ± 3.0	170 ± 60	12.9 ± 0.2	1.8 ± 0.3

Table 3. Inhalable, thoracic, tracheobronchial and respirable mass fractions (% and µg m^{-3}) in healthy adults and high risk population (children, frail or sick people) deposited in the respiratory tract for obtained for combustion phases (F1, F2, F3, F4), background (BG), cleaning process the ashes and embers (CL), and maximum concentration, evaluated following the ISO 7708:1995.

ACTIVITY CODE	Inhalable Fraction	Thoracic Fraction	Tracheobronchial Fraction-Healthy adult	Tracheobronchial Fraction-High risk	Respirable Fraction-Healthy adult	Respirable Fraction-High risk
	(µg m^{-3})	(µg m^{-3})	(µg m^{-3})	(µg m^{-3})	(µg m^{-3})	(µg m^{-3})
F1	194 ± 12	100 ± 40	56 ± 13	70 ± 20	40 ± 30	23 ± 15
F2	273 ± 16	130 ± 50	77 ± 12	100 ± 20	60 ± 40	30 ± 30
F3	94 ± 2	38 ± 7	27 ± 4	32 ± 5	11 ± 4	5 ± 3
F4	79.3 ± 1.8	32 ± 6	24 ± 4	28 ± 5	8 ± 4	4 ± 3
BG	65 ± 5	31 ± 16	24 ± 11	29 ± 15	7 ± 6	2.1 ± 1.8
CL	187.7 ± 1.5	59 ± 5	47.6 ± 1.8	54.3 ± 0.4	11 ± 6	5 ± 4
Maximun	4202	2224	1430	1888	793	336

Table 4. Fine and Accumulation modes: Number of particles, Count Median Diameter (CMD) and Geometric Standard Deviation (σg) of the number distributions obtained for combustion phases (F1, F2, F3, F4), background (BG) and cleaning process of the ashes and embers (CL).

	FINE MODE			COARSE MODE		
CODE	N (cm^{-3})	CMD (µm)	σ_g	N (cm^{-3})	CMD (µm)	σ_g
F1	249	0.23	1.75	5.3	2.28	1.53
F2	159	0.24	1.63	5.0	1.86	2.20
F3	40	0.18	1.75	1.3	1.82	2.46
F4	34	0.17	1.91	0.7	2.77	1.92
BG	8	0.10	2.31	0.4	3.14	2.04
CL	55	0.18	1.81	1.24	2.53	2.26

Table 5. Estimated mass concentrations: TSP, PM_1, $PM_{2.5}$, PM_{10}, >PM_{10} and $PM_{2.5-10}$ to PM_{10} ratio for sequential combustion phases (F1, F2, F3, F4), background (BG), cleaning process of the ashes and embers (CL) for a density indoors of 2.055 g cm^{-3} (estimated from the aerosol composition).

CODE	TSP (µg m^{-3})	PM_1 (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_{10} (µg m^{-3})	> PM_{10} (µg m^{-3})	$PM_{2.5-10}$/PM_{10} %
F1	290 ± 180	18 ± 20	50 ± 60	130 ± 120	160 ± 80	72 ± 13
F2	400 ± 600	14 ± 12	30 ± 30	200 ± 200	200 ± 300	73 ± 15
F3	130 ± 60	3 ± 2	7 ± 3	50 ± 20	90 ± 40	83 ± 6
F4	110 ± 60	1.7 ± 1.5	5 ± 3	40 ± 30	70 ± 40	85 ± 7
BG	90 ± 100	0.3 ± 0.2	1.9 ± 1.1	20 ± 20	60 ± 80	90 ± 5
CL	260 ± 90	3 ± 3	8 ± 7	60 ± 16	200 ± 70	89 ± 8

Table 6. Mass concentration: PM_{10}, OC, EC, TC and ratios OC/PM_{10}, EC/PM_{10}, TC/PM_{10}.

PM_{10} (µg m^{-3})	OC (µg m^{-3})	EC (µg m^{-3})	TC (µg m^{-3})	OC/PM_{10} (%)	EC/PM_{10} (%)	TC/PM_{10} (%)
89 ± 9	24.0± 0.9	3.6± 0.5	27.5 ± 0.3	26.9 ± 1.9	4.1 ± 1.0	31± 3

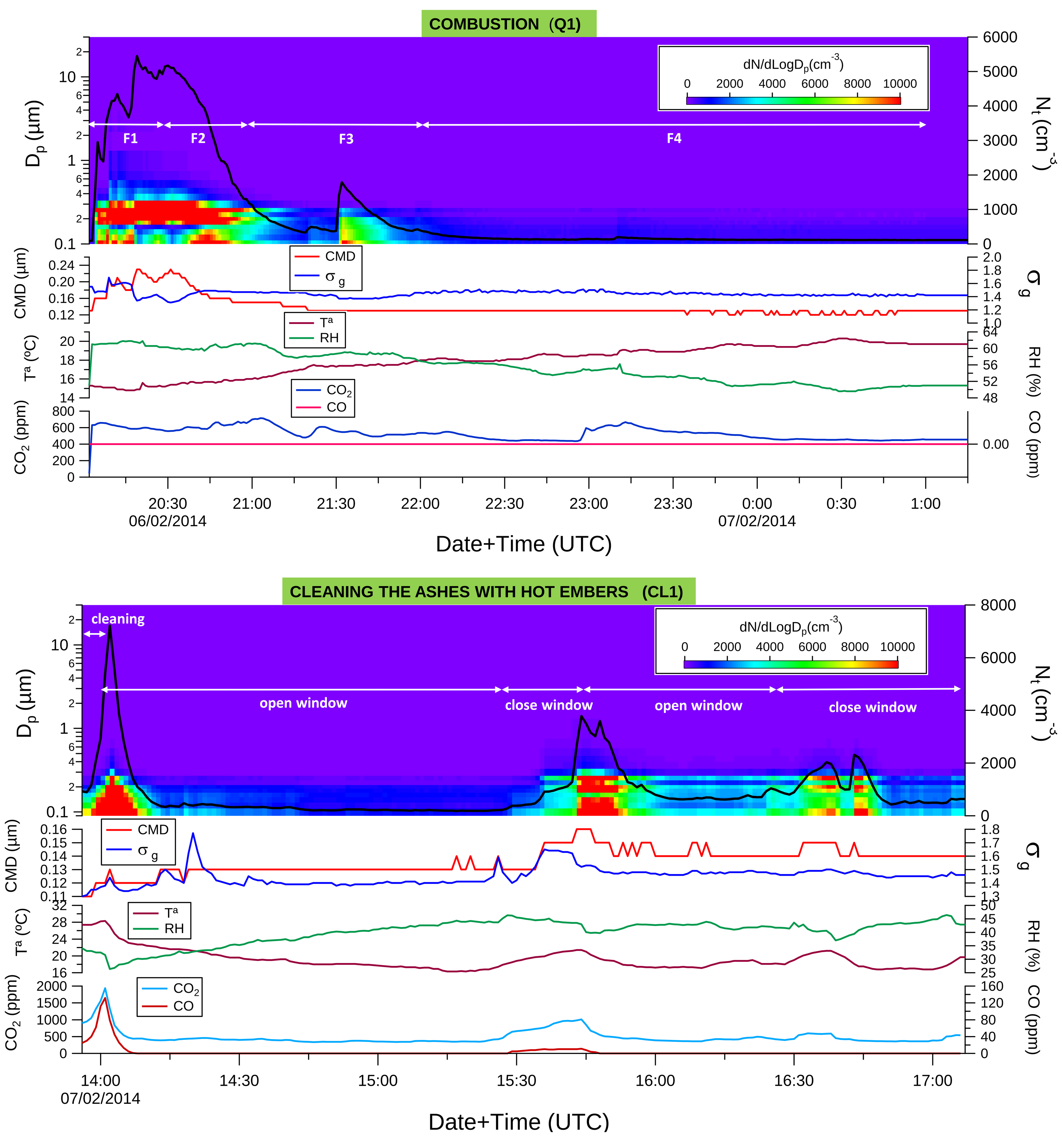

Figure 5. Example of two case studies: a) combustion experiment Q1, where F1 is the startup phase of combustion, with cold fireplace and other three refueling processes F2, F3 and F4, b) cleaning process of the ashes with hot embers (CL1). Evolution of the aerosol size distributions, the total number of particles (Nt), as well as the Count Median Diameter (CMD) and Geometric Standard Deviation (σ_g), Temperature (ºC) and Relative Humidity (%), and CO and CO_2 concentrations.

CONCLUSIONS

- During the combustion of oak logs in an open fireplace, the most critical activities for indoor air quality were related to the "cold" initial temperature of the domestic combustion device and the room surrounding air. The ignition phase (F1) takes time and generates a lot of smoke, with PM_{10} mean values of 370 µg m^{-3}. However, for the subsequent refueling stages, F2, F3 and F4, the particulate concentrations decrease.
- In later combustion processes, when the fireplace and surrounding air were warmed up, PM_{10} values estimated for the F3 and F4 phases were much lower, around 50 µg m^{-3}.
- The process of removing the ash from the fireplace is highly pollutant if small burning embers are hidden. During this cleanup phase, the PM_{10}, CO_2 and CO mean concentrations were 74 µg m^{-3}, 1940 ppm and 132 ppm, respectively.
- For all combustion experiments, the PM_{10} indoor mean concentration was 89 µg m^{-3}.
- Due to the important number of particles with sizes lower than 0.5 µm released to the indoor environment, the cleanup phase could be hazardous to human health. Thus, during the most critical moments (cleanup phase with small burning hidden embers in the ashes) for an healthy adult, a maximum of 800 µg m^{-3} reach the alveolar region (bronchioles and alveoli). However, with a correct cleanup phase (with cold ashes and embers) the mean decreased up to 11 µg m^{-3}. During the initial phases of combustion with cold temperatures, for F1 and F2, the values were 40 ± 30 and 60 ± 30 µg m^{-3}, respectively.

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