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COUPLING OF TWO METHODS TO OBTAIN POLLUTANT EMISSION FACTORS FROM BIOMASS BURNING IN SMALL COMBUSTION SOURCES

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INTRODUCTION

- Biomass burning in developing countries is widely used for cooking food and heating in rural environments, this combustion process is not efficient, and several pollutants are generated such as: CO_2, CO, NOx, SO_2, PM, in addition to SLCF: Short-Live Climate Forcers (CH_4 and EC).
- The estimation of emission inventories of climate forcing species and air pollutants from activities such as the biomass burning from cooking food in rural environments in Mexico presents some degree of uncertainty due to the lack of locally obtained emission factors; emissions estimates were generally obtained with other types of biomass and cookstoves.
- The relevance of these pollutants for Mexico is mainly due to their contribution to air pollution, global warming and negative impacts on human health.
- This study presents an assembly of theoretical-experimental procedures in order to estimate emission factors from improved stoves and other biomass burning processes.

OBJECTIVES

- Using a controlled dilution system to facilitate the sampling of particles and the conditioning of gases to measure them using typical ambient air quality monitoring instrumentation in order to obtain combustion emission samples for the determination of CO_2, CH_4, CO, NMHC, NOx, SO_2, OC, EC, and $PM_{2.5}$.
- Calculation of emission factors from small combustion sources using a controlled dilution, carbon mass balance and concentration ratios with respect to CO_2 and CO.

METHOD

- The gaseous and particulate matter emissions from three biomass cooking stoves were measured by a team of researchers from the Center for Atmospheric Sciences (CCA) and the Center for Ecosystems Research (CIECO), National Autonomous University of Mexico UNAM) following a Water Boiling Test Protocol (WBT), it is a simplified simulation of the cooking process and consists of three consecutive tests: cold start, hot start, and a 45-min simmer period. A compact dilution stack sampler (CDS) was used to sample the emissions (slide 6). The experiment consisted in performing several repetitions of the WBT using white oak (Quercus bicolor) without bark to obtain several sets of data for each of the three stages from which the respective emission factor was obtained and finally a weighted emission factor.
- Dilution sampling is a technique that has been developed to evaluate the influence of rapid cooling and dilution from PM emissions from combustion sources and therefore simulate the aerosol processes that occurs after the quenching, such as coagulation, condensation and nucleation change the size and composition of the PM emissions.

- The CDS consisted of a stainless-steel duct of 20 cm-diameter, 80 cm-length constructed following the design principles of Hildemann et al (1989) and England et al. (2007). The hot stack stream was suddenly diluted and quenched with a large stream of HEPA and charcoal (GAC) filtered ambient air. An undiluted sample rate of 20–25 actual L/min and dilution flow rates of 300–700 L/min were typically used (dilution air ratio in the range of 15:1 – 40:1). A controlled by-pass HiVol fan connected to the chamber extracted the excess of diluted exhaust flow to keep the dilution ratio in the selected set.
- The sampling of PM was performed at one sampling port located at the end of the dilution chamber through a $PM_{2.5}$ cyclone connected to a filter support and a vacuum pump. The material collected in the filters consisted of integrated PM samples for each of the stages of the WBT. The analysis of carbon in the collected PM was carried out with an UIC analyzer CM5014. In addition, continuous measurement of combustion gases and other particle parameters were performed with an instrumented mobile lab connected to another sampling port of the chamber (slide 6).

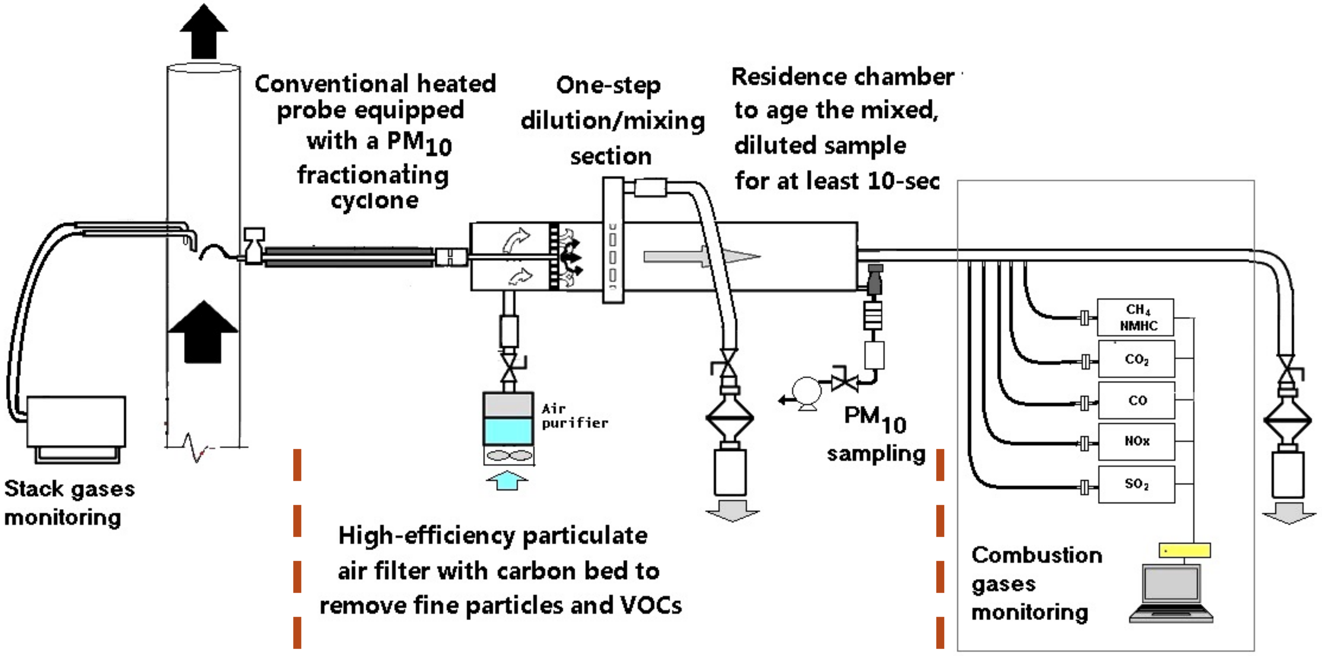
COOKSTOVES

PATSARI

ONIL

ECOESTUFA

THREE STONES



Combustion emission

Controlled Dilution System

Ambient air quality monitoring instrumentation

Carbon balance:

$$gC_{emitted} = gC_{biomass\ burned} - gC_{coal} = g\ wood\ dry\ burned*0.5 - g\ coal*0.81 = \overbrace{gC_{CO2} + gC_{CO} + gC_{CH4} + gC_{TNMHC} + gC_{aerosol}}^{\text{Combustion emission}}$$

Emission Factor: mass ratio of a compound emitted (x) per amount of dry fuel burned

$$EF_x \cong \frac{[x]}{\Sigma\left(\left[C_{CO_2}\right] + [C_{CO}] + \left[C_{CH_4}\right] + [C_{NMHC}] + [C_{aerosol}] + \ldots\right)} * [C]_{biomass}$$

WBT emission factor:

$$EF_{x\ WBT} = \frac{\left(EF_{x,\ 1\ WBT} * C_{emitted,\ 1}\right) + \left(EF_{x,\ 2\ WBT} * C_{emitted,\ 2}\right) + \left(EF_{x,\ 3\ WBT} * C_{emitted,\ 3}\right)}{C_{total\ emitted,\ WBT}}$$

Concentration of carbon in particle matter in the form of organic carbon and elemental carbon:

$$\left[C_{aerosol\ x}\right] = \frac{PM_{2.5}}{t * Q_{STP}} * \frac{\%C_{aerosol\ x}}{100}$$

Carbon concentration of a gaseous species:

$$[C_x] = [x] * \frac{MW_{carbon}}{MW_x}$$

Emission factor of PM2.5:

$$EF_{PM_{2.5}WBT} = FE_{COWBT} * \frac{\Delta\left[PM_{2.5}\right]}{\Delta[CO]}$$

(Padilla-Barrera et al., 2019)

Slope $\frac{[PM_{2.5}]}{[CO]}$ and the R^2 coefficient associated to the correlation of $PM_{2.5}$ vs CO measured at the outlet of the dilution system by stove and stove under the WBT test.

COOKSTOVE	Variable	
	$\frac{[PM_{2.5}]}{[CO]}$	R^2
Patsari	0.05	0.71
Onil	0.05	0.72
Ecoestufa	0.04	0.86
Three stones	0.06	0.89

RESULTS

WBT average emission factors of cookstoves and three stones												
		NO	NO_2	NOx	SO_2	CO	CH_4	NMHC	CO_2	OC	EC	$PM_{2.5}$
		mg/Kg				g/kg						
Patsari	E.F. (WBT)	658.08	260.56	871.58	46.14	63.34	3.13	9.71	1374.78	1.94	0.16	3.17
Onil	E.F. (WBT)	766.96	186.37	935.98	54.60	54.77	2.18	6.83	1472.75	1.79	0.13	2.74
Ecoestufa	E.F. (WBT)	576.39	278.16	798.22	64.15	102.94	4.01	16.78	1309.06	2.89	0.71	4.12
Fogón	E.F. (WBT)	290.38	571.67	696.97	75.00	142.12	4.39	24.03	1191.84	5.53	1.39	8.53

CONCLUSIONS

- The new sampling design allows the **determination of gas and particle emission factors** applying two procedures: **carbon mass balance and concentration ratios with respect to CO_2 y CO.**
- The **final emission factor** consists of a **weighted average** of the factors determined for each species with respect to the amount of carbon oxidized in each of them, obtaining emission factors in terms of g of species emitted / Kg dry wood burned.
- The **Onil** and **Patsari** stoves have certain **similarities** in the magnitude of their emission factors, indicating that the **construction material** of the improved stove also affects the emission factors..
- The **three stones** and the **Ecoestufa** also have **similar emission** factors, the stove is in direct contact with the ambient air, which benefits the **particulate matter formation process** as well as the condensation of volatile organic compounds in the particles and it is possible that the loss of heat in the Ecoestufa through its metal structure is an important factor in combustion efficiency.

- Using **CO FE** as a **tracer of combustion efficiency**, it was found that the more inefficient the process, the greater the emission of NMHC, NO2, PM2.5, OC and EC, and lower that of CO_2 and NO_2.
- **Combustion conditions** are also **affected** by the amount of **oxygen available** in the air. At higher altitudes, the number of oxygen molecules decreases, leading to relatively more incomplete combustion, and therefore higher emission of pollutants and greater impact on the environment. Therefore, the **initial heating process** of the entire upgraded stove before the start of the cooking process also requires a **larger quantity of firewood**.
- Using a sampling protocol like the **WBT**, the samples are **standardized, helping the repeatability** of the experiment and **controlling** the largest number of **variables**.
- The use of the **carbon balance and ratio method** helped to obtain the emission factors without the use of the dilution factor, thus **reducing** the **uncertainty inherent** in the process.
- If the financial budget exists, it is recommended to carry out more repetitions of the samplings of each improved stove.
- Knowing **local emission factors** will help different financial mechanisms and incentives to adapt to **local circumstances** and for clean and efficient **stove programs to be expanded, disseminated and adopted.**

EFFICIENCY

Patsari and Onil		Ecoestufa and Three Stones
CO_2	>	CO_2
CO	<	CO
t	>	t
Firewood consumption	>	Firewood consumption
PM, OC and EC	<	PM, OC and EC
NO	>	NO
NO_2	<	NO_2
SO_2	<	SO_2
CH_4 and HCNM	<	CH_4 and HCNM

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