Supplementary Information

Emission of Metals from Pelletized and Uncompressed Biomass Fuels Combustion in Rural Household Stoves in China

Wei Zhang[1], Yindong Tong[2], Huanhuan Wang[2], Long Chen[2], Langbo Ou[2], Xuejun Wang[2]*, Guohua Liu[1]& Yan Zhu[1]

1. School of Environment and Natural Resources, Renmin University of China, Beijing 100872, China

2. Ministry of Education Laboratory of Earth Surface Processes, College of Urban and Environmental Sciences, Peking University, Beijing 100871, China

S1. Properties of the biomass fuels

Table S1 Properties of the tested biomass pellets and raw biomass fuels

Parameter	Pine wood pellet	Corn straw pellet	Pine wood chip	Corn straw
Component	Chinese pine (*Pinus tabuliformis*)	Corn stalks (*Zea mays*)	Chinese pine (*Pinus tabuliformis*)	Corn stalks (*Zea mays*)
Place of origin	Beijing	Beijing	Beijing	Beijing
Diameter (mm)	6	8	-	-
Ash content (%)	3.7	10.8	0.3	4.0
Higher heating value (MJ/kg)	17.83	15.24	18.51	17.26
Density (g/cm^3)	1.3	1.4	0.4	0.07
Volatile matter (%)	76.77	70.62	84.77	77.94
Moisture (%)	5.63	5.80	9.10	7.02
Fixed carbon (%)	19.48	18.54	14.98	18.05
H (%)	5.84	5.48	6.32	6.02
C (%)	46.78	43.14	49.10	43.47
N (%)	0.16	1.23	0.18	0.96
Cl (%)	0.35	1.30	0.02	0.77

S2. Combustion condition

For combustion of the biomass fuels, parameters including modified combustion efficiency (MCE), product of incomplete combustion (PIC) and burning rate (R_b) were calculated to describe the combustion conditions. There parameters are listed in Table S2, and the calculation formulas are:

$$MCE = \frac{C_{CO_2}}{C_{CO_2} + C_{CO}} \quad (1)$$

where C_{CO2} and C_{CO} are the concentrations of CO_2 and CO emitted from the fuel combustion.

$$PIC = \frac{C_{C-CO} + C_{C-PM} + C_{C-THC}}{C_{C-CO_2}} \quad (2)$$

where $C_{C\text{-}CO2}$, $C_{C\text{-}CO}$, $C_{C\text{-}THC}$ and $C_{C\text{-}PM}$ are carbon released as CO_2, CO, total hydrocarbon (THC) and in particle matter (PM), respectively.

$$R_b = \frac{M}{t} \quad (3)$$

where M (g) is the mass of biomass fuels burnt, t (min) is the time of whole burning cycle.

Table S2 Combustion parameters for biomass pellets and raw biomass fuels.

Parameter	Pine wood pellet	Corn straw pellet	Pine wood chip	Corn straw
MCE (%)	99.7±2.6	96.3±3.4	92.2±3.7	95.9±1.6
PIC (%)	0.426±0.003	4.99±1.24	3.96±1.23	4.15±0.41
R_b (g/min)	18.5±0.7	9.5±0.5	83.5±4.9	44.1±2.5

S3. Regression analysis

A number of factors including moisture, ash content, C, H, Cl and N of the fuels, MCE, Rb, and VM were assessed for their influences on EFs using a stepwise regression model. It was revealed that moisture, VM and MCE were included in the regression model. Therefore, the equation to predict EFs of the tested metals can be expressed as follows:

$$EF_s = a + b \times \mathrm{M} + c \times \mathrm{VM} + d \times \mathrm{MCE}$$

Where a, b, c and d are the calculated regression coefficients, and M (moisture), VM and MCE are in unit of %. The regression coefficients and the coefficient of determination (R^2) are summarized in Table S3.

Table S3 Results of regression analysis on EFs of Pb, Cu, Cd, As and Ni.

Regression coefficient		Pb	Cu	As	Cd	Ni
a	Unstandardized Coefficients	1399.31	2586.21	7967.95	35.323	274.83
	Standardized Coefficients	-	-	-	-	-
b	Unstandardized Coefficients	-54.316	-100.71	-326.53	-1.390	-10.493
	Standardized Coefficients	-40.039	-62.2	-40.496	-40.169	-37.109
c	Unstandardized Coefficients	7.585	14.345	47.789	0.199	1.452
	Standardized Coefficients	20.273	32.123	21.488	20.879	18.622
d	Unstandardized Coefficients	-16.772	-31.241	-97.945	-0.428	-3.274
	Standardized Coefficients	-23.458	-36.611	-23.049	-23.464	-21.97
Coefficient of determination (R^2)		0.882	0.894	0.971	0.436	0.736

S4. Calculation of task-based emission factors

Since different amounts of biomass fuels are needed for the same cooking task using different fuel/stove combinations, task-based emission factors are better than mass-based factors for comparing the air pollution potential of different fuel/stove combinations. The calculation formulas are:

$$\mathrm{EF_{task\text{-}energy}} = \frac{EF_{mass}}{HV \times \eta} \times J$$

$$\mathrm{EF_{task\text{-}time}} = EF_{mass} \times R_b \times T \times 60$$

Where $EF_{task\text{-}energy}$ (mg/MJ) represents the mass of metal emissions from delivering unit mega-joule heat to the pot by a given fuel/stove combination. $EF_{task\text{-}time}$ (mg/hr) represents the mass of metal emissions from unit cooking time. EF_{mass} (mg/kg) is the EFs based on fuel mass. HV (MJ/kg) is the upper-heat calorific value of biomass fuels. η is stove efficiency (%). J (MJ/task) is the energy delivered to the pot per task, and here was defined as 1 MJ heat to the pot. HV was measured in the study and η was cited from literature [1]. R_b is burning rate (kg/min). T is cooking time, and here was defined as 1 hr.

Table S4 Parameters for calculation of the task-based emission factors

Equipment	Biomass	HV (MJ/kg)	η (%)[1]	HV*η
Pellet burner	Pine wood pellet	17.83	43	7.67
	Corn straw pellet	15.24	43	6.55
Conventional stove	Pine wood chip	18.51	13	2.41
	Corn straw	17.26	13	2.24

[1] cited from Fan et al., 2010

Additional References

1. Fan X., Lv Z., Li D., Yu X. Performance of cooking stoves with biomass pellet fuel. Transactions of the Chinese Society of Agricultural Machinery 26(2): 280-284 (2010). (in Chinese with English abstract)