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Determination of the Emission Factors from Burning Common Domestic Cooking Fuels in Vietnam and its Application for Calculation of their Pollution Load

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Abstract

The emission factors and the air pollution load of domestic cooking processes in Vietnam were investigated. All the measurement results were given from experiments implemented at equipment imitated common cooking ways of almost households in different areas of Vietnam. The commonly used fuels concerning to the investigation were fuel gas, kerosene, comb coal, fossil coal, firewood, straw and rice stubble. The main parameters emitted from fuel burning processes such as SO_2, NO_x, CO, TSP and PM_{10} and related parameters such as temperature, pressure, exhaust gas flow rate were measured by the suitable equipment. Based on the measurement data, emission factors and pollution load were calculated and compared with other data published in the world.

Keywords: cooking fuel; emission factor; pollution load

1. Introduction

Air pollution is a problem concerning burning fuels every day in all countries in the World. Besides industrial activities, the domestic area contributed a significant quantity of pollutants to air environment. Vietnam population up to now is about 90 million living in locations with different living conditions, and the ways of their fuel use are different too. The common fuels for domestic use in Vietnam are straw, rice stubble, firewood, comb coal, fossil coal, kerosene and fuel gas. There had not been official data of emission factors and pollution load of this area published yet in Vietnam before our investigation. Therefore the determination of emission factors and pollution load of domestic exhaust gas was necessary and useful for other concerning activities. The annual using portion of these fuel kinds is variable but it can be able to determine approximately at fixed time in pointed location.

2. Materials and Methods

2.1. Materials

The fuels used in our investigation include most common matter used for cooking purpose. Based on the field survey and statistic data (Hanoi Statistics Office, 2010), the kinds of the fuels were selected as below:

- Straw and rice stubble were collected from rice fields after harvest season and dried naturally
- Firewood was collected as tree branches and wood matter waste from wood processing factories and civil construction area and dried naturally.
- Comb coal was collected from comb-coal dealer with two types. One was normal comb coal and the other was “quick-catch-fire” one.
- Fossil coal was powder fossil coal as a refuse from coal processing factories and when it takes for cooking, the powder was mixed with about 10% mud.
- Kerosene was collected from petrol dealer stations
- Fuel gas was commercial and it was held in standard pressed metals bottle for cooking purpose.

Burning fuels realized in devices imitating common cooking work in almost households in Vietnam. The devices were selected as below:

- Cooking tripod used for burning straw, rice stubble and firewood
- Different stoves used for burning other fuels such as comb coal stoves, common gas stoves, fossil coal stoves, kerosene stoves (cotton fiber wick type).

2.2. Experimental Methods

In order to isolate exhaust gas and lead it to the measurement mouth, the fuel was burned in the chimney with the shape as described in Fig. 1. The total height of the chimney is 4.31 m that is equal to height of common kitchen roof and divided into 3 parts. The low part (1) with dimension 0.9 x 1.3 m is burning chamber where the burning devices posited in. The middle part (2) with dimension 0.8 x 1.75 m is circulation area and the upper part (3) with dimension 0.11 x 1.26 m is cooler area where the hole (5) is posited about 0.25 m lower from chimney mouth (4) for measure heads put in. The chimney has equipped the door (6) for fuel burning operation.

The monitoring parameters were measured continuously time to time (t_1, t_2,...t_n) just from ignition to the moment when measuring level of the parameter is approximately ambient level.

The concentration of CO, SO_2, NO_x, pressure and temperature of the exhaust gas were measured by the multifunction equipment KM – QUINTOX, KANE (UK brand). TSP and PM_{10} were measured by MICRODUST-PRO, Cacella (USA brand). Exhaust flow rate was measured by TESTO 350 XL (Germany brand). Concentration of CO, SO_2, NO_x, TSP and PM_{10} of ambient air beside the chimney were determined by normal monitoring method used for calculation and data correction.

2.3. Calculation methods

Instantaneous emission rate (M_{Xi}) of substance X at the measured time t_1, t_2,...t_n is calculated by formula (1).

$$M_{Xi} = N_i.L_i \quad (1)$$

Where M_{Xi} (mg/s) is the emission rate of substance X at time t_i; N_i (mg/m^3) is concentration measured at time ti and Li is instantaneous flow of exhaust gas

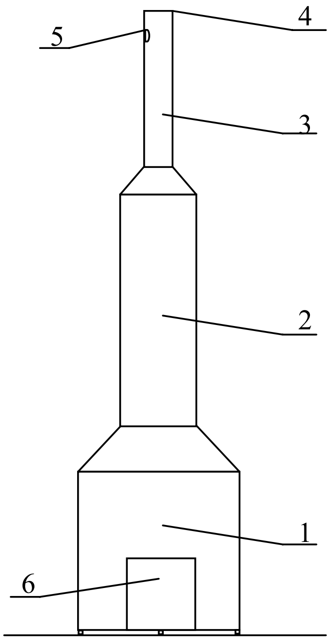

Figure 1. The chimney.

measured at time t_i (L_i = S.v_i; S is cross section of upper part of the chimney and v_i is exhaust gas flow rate measured at time t_i).

For following calculation, all instantaneous values measured in real conditions will be changed into normal values according to standard conditions of pressure and temperature by formula (2).

$$V_i = \frac{P_0 V_0 T_i}{T_0 P_i} \quad (2)$$

where P_0 = 1 atm, V_0 = 1 Nm^3 and T_0 = 298^0K are standard conditions and V_i, P_i and T_i are values measured in real conditions at time t_i.

- The particular value of substance concentration emitted from fuel burning (N_{ih}) is calculated by formula (3).

$$N_{ih} = N_i^* - N_{i0}^* \quad (3)$$

Where N_i^* and N_{i0}^* is concentration of the substance adjusted to standard conditions.

- The average value of emission rate adjusted to standard conditions ($\overline{M}_x^*$) is calculated by formula (4).

$$\overline{M}_x^* = \frac{1}{n}\sum_{i=1}^{n} N_{ih} L_i^* \quad (4)$$

- The emission factor of pollutant X (EF_x) is the ratio between the total emission quantity of X and the amount of burned fuel was calculated by formula (5).

$$EF_x = \frac{\overline{M}_x^*.t}{m} \quad (5)$$

Where t is toal measuring time (s), m is amount of burned fuel (kg).

- The evaluation of standard deviation of the emission factor determination, the mean value of EF_x, the variance σ_x^2, the standard deviation σ_x, and relative errors ε_x were calculated following formulas (6), (7), (8), and (9).

$$\overline{EF}_x = \frac{1}{3}\sum_{i=1}^{3} EF_{xi} \quad (6)$$

$$\sigma_x^2 = \frac{1}{2}\sum_{i=1}^{3}\left(EF_{xi} - \overline{EF}_x\right)^2 \quad (7)$$

$$\sigma_x = \pm\sqrt{\frac{1}{2}\sum_{i=1}^{3}\left(EF_{xi} - \overline{EF}_x\right)^2} \quad (8)$$

$$\varepsilon_x = \frac{|\sigma_x|}{\overline{EF}_x}100\% \quad (9)$$

- Fuel consumption survey:

As mentioned above, the different kinds of households are using different fuels and their consumption is different. Therefore, for more correction of calculation values of fuel consumption, the households were divided into groups, each group has similar living conditions and activities (for example: households in urban and suburban areas, households in old apartments, in high-rise buildings, in country side, the hotels, the restaurants, the serving etc.).

In order to estimate (extrapolate) average value (μ) for a representative group, the number of survey households (N) must be satisfied condition $N - 1 \geq 121$ (Ho and Loan, 2001) to meet the normal distribution law "Student" with an error of $\alpha = 0.05$ (it means the probability is 95% to ensure the reliability of extrapolated average value μ). So, the minimum number of households surveyed was selected 122.

The scientific basis for calculation of average value of samples ($\overline{X}$) based on the basic probability and statistic theory. For example, for N survey in N households, there are n households using one kind of the fuel, so the rate of households using this fuel is f = n/N (the f also called frequency in statistical probability theory). Consider that X is a random function, then $X = X(x_1, x_2,..., x_n)$, where $x_1, x_2,..., x_n$ are the amounts of the fuel used in n households with frequency f. Based on the actual surveyed values of $x_1, x_2,...x_n$, the average value ($\overline{X}$) can be calculated by formula:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \text{ (kg/day/household)} \quad (10)$$

With n random value of x from total N households, the mathematical expectation $EX = \mu$ need to be in certain interval ($\mu_1 \leq \mu \leq \mu_2$) with a given error α. So, the result of an estimated interval for μ with reliability $1-\alpha$ is:

$$\mu = \overline{X} \pm \varepsilon \quad (11)$$

where $\varepsilon = t_{N-1(\alpha/2)}.\sigma_x / \varepsilon = t_{N-1(\alpha/2)}.\sigma_x / \sqrt{(N-1)}$ (extrapolated parameter); $t_{N-1(\alpha/2)}$ is student distribution with (N–1) freedom degrees; σ_x is standard deviation of X.

Combination formula (11) with frequency f obtains formula:

$$\overline{\mu} = \overline{Xf} \pm \overline{\varepsilon f} \quad (12)$$

- Estimating total amount of the fuel type

Suppose that, formula (12) estimates amount of fuel used for each kind of fuel j is Q_j (tone/year) in Hanoi including households in urban and suburban areas we have formula:

$$Q_j = \overline{\mu}_{j1}.H_1 + \overline{\mu}_{j2}.H_2, \quad (13)$$

Where $\overline{\mu}_{j1}.H_1$ is total amount of fuel type j consumed in households in urban area and $\overline{\mu}_{j2}.H_2$ is corresponding to suburban area; H_1, H_2 are the total number of households in urban and suburban area.

- The pollution load of substance x from fuel type j. The pollution load M_{xj} is calculated by formula (14).

$$M_{xj} = \overline{EF}_{xj} \times Q_j \quad (14)$$

Where $\overline{EF}_{xj}$ is the emission factor of substance x (Table 1).

3. Results and discussion

3.1. Emission factor of the common fuel using in Vietnam

The emission factors $\overline{EF}$ of substance x (SO_2, NO_x, CO, TPS, PM_{10}) corresponding to the type of fuel (straw, rice stubble, firewood, comb coal, fossil coal, kerosene, fuel gas) were calculated and listed in Table 1.

The mean emission factors $\overline{EF}$ (g/kg) of substances of SO_2, NO_x, CO, PM_{10} and TSP corresponding to with 8 types of surveyed fuels calculated by the method of the CEMM (table 1) show that: $\overline{EF}$ of SO_2 has the greatest value by 15.97 (comb coal) and the least value by 1.64 (fire wood); $\overline{EF}$ of NO_x has the greatest value by 4.47 (fuel gas) and the least value by 1.36 (fossil coal); $\overline{EF}$ of CO has the greatest value by 123.26 (fire wood) and the least value by 1.4 (fuel gas); $\overline{EF}$ of PM_{10} has the greatest value by 1.94 (firewood) and the least value by 0.04 (fuel gas); $\overline{EF}$ of TSP has the greatest value by 7.08 (fire wood) and the least value by 0.48 (fuel gas)

The overall assessment has showed that the emission factors $\overline{EF}$ of pollutants created from the types of the fuels such as comb coal, fossil coal, firewood, straw and rice stubble have the much higher values in comparison with the emission factors of pollutants from kerosene and fuel gas. Except that only the emission factor of NO_x emitted from the gas fuel has the highest values. This can be explained as follows: Generally, NO_x was generated by oxidation–reduction reaction of compounds containing nitrogen when they were burned. Besides that, a lot of studies showed NO_x can be created from N_2 and O_2 in the air under particular conditions such as high temperature, in contact with unintentional catalyst (metals or metal oxide) or both, especially in the boundary of fuel gas flame.

3.2. Comparison between emission factor values of our experiment and others published

The table 2 shows that 1) Straw: $\overline{EF}$ of CO (CEMM) is approximately $\overline{EF}$ (Nepal), but 2.7 times higher than $\overline{EF}$ (India); $\overline{EF}$ of TSP (CEMM) is 3 times higher than $\overline{EF}$ (India). 2) Fire wood: $\overline{EF}$ of CO (CEMM) is approximately $\overline{EF}$ (USEPA) and 0.68 times lower than $\overline{EF}$ (China) and about 1.5 times higher $\overline{EF}$ (NAEI, India, IPCC). 3) Comb coal: $\overline{EF}$ of CO (CEMM) is 0.78 times lower than $\overline{EF}$ (China). 4) Fossil coal: $\overline{EF}$ of SO_2 (CEMM) is approximately $\overline{EF}$ (DE); $\overline{EF}$ of NO_x (CEMM) is 0.59 times lower than $\overline{EF}$ (DE); and $\overline{EF}$ of CO (CEMM) is 0.8 times

Table 1. The calculated values of emission factors $\overline{EF}_x$ (g/kg), standard deviation σ_x (g/kg), and relative error ε_x based on the experimental data.

	SO_2	NO_x	CO	PM_{10}	TSP		SO_2	NO_x	CO	PM_{10}	TSP
1. Straw						5. Quick-catch-fire comb coal					
$\overline{EF}_x$	1.687	2.681	69.179	0.633	6.149	$\overline{EF}_x$	10.145	1.678	35.027	0.838	3.580
σ_x	0.079	0.126	3.257	0.030	0.493	σ_x	0.195	0.035	0.688	0.016	0.158
ε_x	0.047	0.047	0.047	0.047	0.080	ε_x	0.019	0.021	0.020	0.019	0.044
2. Rice Stubble						6. Fossil coal					
$\overline{EF}_x$	2.613	3.505	43.654	0.629	2.794	$\overline{EF}_x$	13.318	1.362	38.900	0.996	1.972
σ_x	0.044	0.061	0.730	0.011	0.013	σ_x	0.311	0.032	0.909	0.023	0.129
ε_x	0.017	0.017	0.017	0.017	0.005	ε_x	0.023	0.023	0.023	0.023	0.065
3. Firewood						7. Kerosene					
$\overline{EF}_x$	1.636	2.677	123.262	1.941	7.084	$\overline{EF}_x$	-	3.486	4.202	0.064	0.729
σ_x	0.041	0.066	3.057	0.048	0.255	σ_x	-	0.181	0.087	0.003	0.080
ε_x	0.025	0.025	0.025	0.025	0.036	ε_x	-	0.052	0.021	0.047	0.110
4. Comb coal						8. Fuel gas					
$\overline{EF}_x$	15.973	1.844	78.947	1.107	5.470	$\overline{EF}_x$	-	4.742	1.410	0.039	0.484
σ_x	0.260	0.030	1.287	0.018	0.153	σ_x	-	0.121	0.039	0.001	0.024
ε_x	0.016	0.016	0.016	0.016	0.027	ε_x	-	0.026	0.028	0.026	0.050

Note: (-) No data

lower than $\overline{EF}$ (DE). 5) Kerosene: $\overline{EF}$ of CO (CEMM) is 0.23 times lower than $\overline{EF}$ (USEPA) and 4.6 times higher than $\overline{EF}$ (IPCC). 6) Fuel gas: $\overline{EF}$ of CO (CEMM) is 2.8 times higher than $\overline{EF}$ (China), 0.7 times lower than $\overline{EF}$ (IPCC) and 0.1 times lower than $\overline{EF}$ (USEPA).

The differences between $\overline{EF}_x$ (CEMM) and $\overline{EF}_x$ of some countries in the World can be caused by quality and composition of the types of fuels as well as combustion modes under the different climate conditions of each country

3.3. The pollution load caused by the domestic area in Ha Noi

Table 3 shows that pollution load M_{xj} (tonne / year) of SO_2, NO_x, CO, PM_{10} and TSP emitted from the fuels such as straw and rice stubble, firewood, coal and fuel gas have the greatest and the least values as follows: 1) Straw and Rice stubble: Pollution load M_j of CO has the greatest value (9,290.19) and M_j of PM_{10} has the least one (103.74). 2) Firewood: M_j of CO has the greatest value (166,545.00) and M_j of SO_2 has the least one (2,215.92). 3) Comb coal: M_j of CO has the greatest value (36,068.60) and M_j of PM_{10} has the least one (507.11). 4) Fossil coal: M_j of CO has the greatest value (10,716.48) and M_j of PM_{10} has the least one (272.73). 5) Fuel gas: M_j of CO has the greatest value (172.47) and M_j of PM_{10} has the least one (4.89).

Total pollution load ΣM_j emitted from straw and rice stubble, firewood, coal and fuel gas shows that: ΣM_j of CO has the greatest value (222,792.73 tonnes/year) and ΣM_j of PM_{10} has least one (3,523.25 tonnes/year). Table 3 also shows that the pollution load of substances emitted from fuel gases is much less in comparison with what created from other fuels. This remark is the basis to warn the local authorities in the field of environmental protection and management in the country to have strict control measures and route for cutting down polluting fuels such as coal, firewood and straw and rice stubble. Towards the near future, only the fuels such as fuel gas, electricity and other clean fuels should be used for cooking.

4. Conclusions

According to QA/QC assessment for the determination of emission factors of pollutants from domestic sources in the surveyed areas, the relative standard error of this method was determined in the interval of 1 to 11%. These results are reliable and acceptable.

The calculation process and experimental method built for this investigation can be applied in determination of emission factor and estimation of the total pollution load from domestic sources throughout the country instead of using foreign data as before.

The values of emission factors of the same fuel type determined by CEMM, Vietnam in comparison with the values determined in other countries were more less different. The seasons can be caused by different quality and composition of the fuels, by unidentified investigation methods etc., but the data presented in this paper can be a good reference for others concerning

Table 2. Emission factors (g/kg) determined by our experiment (CEMM) in comparison with other published in the World.

Kind of fuel	Location	Emission Factors (g/kg)						References
		SO_2	NO_x	CO	PM_{10}	TSP	PM	
Straw	CEMM, Vietnam	1.69	2.68	69.18	0.63	6.15	-	
Straw	Nepal	-	-	75	-		-	Bhattacharya SC, Abdul Salam P, 2002
Straw	India	-	-	25	-	2.4	-	Bhattacharya SC, Abdul Salam P, 2002
Rice stubble	CEMM, Vietnam	2.61	3.50	43.65	0.63	2.79	-	
Agricultural Waste	China	-	-	160	-	-	10	Yukata Tonooka, 2006
Agriculture Residue	Indonesia	-	-	92 (±84)	-	-	13	Savitri Garivait, 2006
Firewood	CEMM, Vietnam	1.64	2.68	123.26	1.94	7.08	-	
Firewood	USEPA (AP-42)	-	-	126.3		-	-	USEPA, 1996
Firewood	NAEI (UK)	-	0.72	99	7.9	-	-	DE, 2003
Firewood	Vietnam	-	-	-	-	-	4.7	Kim Oanh NT, 2005
Firewood	India	0.6	0.7	80	-	9	-	Bhattacharya SC, Abdul Salam P, 2002
Firewood	Nepal	0.2	1.4	-	-	15	-	Bhattacharya SC, Abdul Salam P, 2002
Firewood	Vietnam	-	0.07 (±0.001)	38.6 (±1)	-	-	-	Bhattacharya SC, Albina. DO, 2002
Firewood	China	-	-	180	-	-	13	Yukata Tonooka, 2006
Firewood	IPCC	-	-	80	-	-	-	Vandana Naidu, 2004
Comb coal	CEMM, Vietnam	15.97	1.84	78.95	1.10	5.47	-	
Comb coal	China	-	-	100	-	-	2.5	Yukata Tonooka, 2006
Comb coal		-	-	-	-	-	1.1	Kim Oanh NT, 2005
Quick-catch-fire comb coal	CEMM, Vietnam	10.15	1.68	35.03	0.84	3.58	-	
Fossil coal	CEMM, Vietnam	13.32	1.36	38.9	0.99	1.97	-	
Fossil coal		13	2.3	46.4	3.7	-	-	DE, 2003
Kerosene	CEMM, Vietnam	-	3.49	4.20	0.06	0.73	-	
Kerosene	USEPA (AP-42)	-	-	17.7	-	0.5	-	USEPA, 1996
Kerosene		-	-	-	-	-	0.3	Kim Oanh NT, 2005
Kerosene	IPCC	-	-	0.9	-	-	-	Vandana Naidu, 2004
Fuel gas (LPG)	CEMM, Vietnam	-	4.74	1.41	0.04	0.48	-	
Fuel gas (LPG)	China	-	-	0.5	-	-	0.5	Yukata Tonooka, 2006
Fuel gas (LPG)	IPCC	-	-	2	-	-	-	Vandana Naidu, 2004
Fuel gas (LPG)	USEPA (AP-42)	-	-	14.9	-	0.51	-	USEPA, 1996

Table 3. The pollution load emitted by fuels from cooking activities in Ha Noi

Kind offuel j	Total fuel amount Q_j (tonne/year)	Pollution load $M_{xj} = Q_j \times \overline{EF}_{xj}$ (tonne/year)		
		SO_2	NO_x	CO
Straw and Rice stubble	164,661 ± 28,027	354.02 ± 60.26	508.80 ± 86.61	9,290.19 ± 1,581.31
Firewood	1,351,168 ± 218,637	2,215.92 ± 358.57	3,621.13 ± 585.95	166,545.00 ± 26,949.20
Comb coal	456,854 ± 49,515	7,295.95 ± 790.76	840.61 ± 91.11	36,068.60 ± 3,909.23
Fossil coal	275,488 ± 33,171	3,669.50 ± 441.84	374.66 ± 45.11	10,716.48 ± 1,290.37
Fuel gas	122,315 ± 16,123	-	579.76 ± 76.42	172.47 ± 22.73
Total	2,370,486 ± 345,474	13,535.39 ± 1,651.43	5,924.98 ± 885.20	222,792.73 ± 33,752.84

Kind of fuel j	Total fuel amount Q_j (tonne/year)	Pollution load $M_{xj} = Q_j \times \overline{EF}_{xj}$ (tonne/year)	
		PM_{10}	TSP
Straw and Rice stubble	164,661 ± 28,027	103.74 ± 17.66	736.04 ± 125.28
Firewood	1,351,168 ± 218,637	2,634.78 ± 426.34	9,566.27 ± 1,547.95
Comb coal	456,854 ± 49,515	507.11 ± 54.96	2,498.99 ± 270.85
Fossil coal	275,488 ± 33,171	272.73 ± 32.84	542.71 ± 65.34
Fuel gas	122,315 ± 16,123	4.89 ± 0.65	58.71 ± 7.74
Total	2,370,486 ± 345,474	3,523.25 ± 532.45	13,402.72 ± 2,017.17

investigation and helpful for managers and local authority activities in environmental control and protective field.

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