

On the determination of nitrous oxide emission factor during biomass burning*

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Abstract—The emission factors of nitrous oxide have been determined during the combustion of rice straws, maize stalks and wheat stalks in an enclosed combustion system. They equal to $84.4 \pm 6.08\text{g/t}$ for rice straws, $132 \pm 8.63\text{g/t}$ for maize stalks, and $27.3 \pm 1.79\text{g/t}$ for wheat stalks, respectively. The uncertainties in the determination of nitrous oxide have been discussed. The $\text{N}_2\text{O-N}$ (nitrogen in nitrous oxide emission) accounts for 0.59% and 0.87% of the total nitrogen in rice straws and maize stalks, respectively. An $1^\circ \times 1^\circ$ grid map on the distribution of N_2O emission from biomass burning in China mainland was shown.

Keywords: biomass burning; nitrous oxide; emission factor.

1 Introduction

The combustion of biomass plays an important role in the developing countries. Crop residues and firewood are widely used for cooking and space heating in the vast rural areas. In recent years, a large fraction of crop residues is no longer used as fuel here in China, but is burned in the fields. Due to incomplete and inefficient combustion of biomass matter, the nitrous oxide emission should be expected to be significant.

The emission of nitrogen-containing compounds from biomass burning has been studied (Jurgen, 1990). Using a simulation open-fire burning apparatus, Jurgen (Jurgen, 1990) analyzed the nitrogen-containing compounds in the exhausts. Since the emission factors for biomass burning are sensitive to changes in combustion conditions (Cofer, 1990), the data obtained from large-scale open fires may not be appropriate to the small-scale enclosed and semi-enclosed combustion. Thus, in this report an enclosed burning apparatus was employed for the determination of nitrous oxide concentrations during the combustion of stalks, stems and leaves of main crops in China. The results expressed as emission factors ($\text{g N}_2\text{O t}^{-1}$) are consistent with the results

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obtained from open burning systems (Jurgen, 1990).

The early studies in the literature on nitrous oxide emission from biomass burning had an artifact associated with the collection and storage of biomass combustion samples (Levine, 1990). Consequently, special attention has been paid to the experimental determination of nitrous oxide.

2 Experimentals

2.1 Apparatus for emission factor determination

It consists of a combustion chamber, a wire-gauze bed support, ignition coil, thermo-couples and thermometers. The combustion chamber is an enclosed rectangular chamber with a volume of 321 L. The bed support is a small wire-gauze basket, in which the crop residues were contained.

Exhaust gas samples were collected in plastic sampling bags with aluminum lining with the aid of a model F-601 gas sampling pump. Moisture and particles in the samples were removed through the cold trap and filter in the sampling system.

A gas chromatographic instrument of the type of SP-3410 (Varian Inc.-Beijing Analyzer Factory) with an 8 mCi Ni⁶³ electron capture detector (Varian Inc., U.S.A.) was used. A calibration gas of 0.940 ppm of N₂O/air was provided by Matheson Gas Products Inc.

2.2 Experimental procedures

5g of crop residues about 15 cm in length was put on the bed support. The bed support was placed in the central part of the combustion chamber about 10 cm above the floor. Biomass is heated and ignited by a Nichrome heating coil. The exhaust gas was contained in the combustion room. The temperature rise during the combustion was recorded by thermo-couple-mV recorder.

Gas samples were collected into 1 L sampling bags and temperature change in the combustion room was recorded simultaneously. Prior to sampling, the sample system was purged with the sampling gas to prevent the adsorption of the constituents of the sample gas in the system. To reduce experimental errors, collection of gas samples was completed within one minute after the extinction of fire in the chamber.

2 ml of sample-gas was taken for the chromatographic analysis of N₂O. A standard gas of 0.940 ppm N₂O/air was used as the calibration gas. Before each run, the background concentration of nitrous oxide in the chamber was also determined.

3 Results

Peak heights of nitrous oxide in the exhaust gas samples were obtained by

chromatographic analysis and listed in Table 1.

Table 1 Nitrous oxide concentration in exhausts during rice-straw burning

Peak height of N ₂ O in sample, cm	31.6	29.6	29.6	27.0	26.2	24.0	24.0	28.0	23.0	24.0	22.0	20.0
Peak height of N ₂ O in background, cm	11.5	11.0	10.0	10.0	10.0	10.4	8.8	9.8	7.6	8.2	8.2	8.2
Peak height of standard N ₂ O*, cm	29.4	29.4	29.4	29.4	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9
Concentration of N ₂ O in sample, ppm	0.64	0.60	0.63	0.54	0.67	0.56	0.62	0.75	0.62	0.65	0.57	0.49

* The concentration of N₂O in the standard gas is 0.94 ppm.

Chromatographic peak heights of nitrous oxide in exhausts during maize- and wheat-stalk burning were obtained in the same way as illustrated in Tables 2 and 3.

Table 2 Nitrous oxide concentration in exhausts during maize stalk burning

Peak height of N ₂ O in sample, cm	41.0	43.0	47.0	43.0	49.0	47.0	46.0	46.0	45.0	41.0	39.0	43.0
Peak height of N ₂ O in background, cm	12.0	11.0	11.0	12.1	12.0	10.8	12.1	10.8	11.7	10.6	10.0	10.0
Peak height of standard N ₂ O*, cm	32.3	32.3	32.3	35.5	34.7	34.7	34.7	34.7	32.0	32.0	32.0	32.0
Concentration of N ₂ O in sample, ppm	0.845	0.931	1.047	0.817	1.003	0.982	0.919	0.955	0.978	0.893	0.851	0.969

* The concentration of N₂O in the standard gas is 0.94 ppm

Table 3 Nitrous oxide concentration in exhausts during wheat stalk burning

Peak height of N ₂ O in sample, cm	13.6	12.0	12.3	12.4	12.1	14.0	13.5	13.2	13.5
Peak height of N ₂ O in background, cm	8.6	6.8	6.8	7.2	7.2	7.5	7.5	7.5	7.5
Peak height of standard N ₂ O*, cm	7.6	7.2	7.2	8.0	7.5	8.5	8.5	8.5	8.5
Concentration of N ₂ O in sample, ppm	0.208	0.223	0.237	0.193	0.202	0.232	0.211	0.198	0.198

* The concentration of N₂O in the calibration gas is 0.32 ppm

During biomass combustion, the volume of air in the chamber expands as the temperature rises. Hence, a volume correction of the total volume of exhaust gas is necessary. Emission factors of nitrous oxide from rice straw, maize stalk and wheat stalk burning are listed in Table 4. The emission factors of nitrous oxide and their standard deviations are: 84.4 ± 6.08 g/t for rice straws, 132 ± 8.63 g/t for maize stalks, and 27.3 ± 1.79 g/t for wheat stalks, respectively.

Table 4 Emission factors of N_2O in exhausts from rice straw, maize stalk and wheat stalk burning

Number of runs	1	2	3	4	5	6	7	8	9	10	11	12	\bar{x}	σ_{n-1}
E^* for rice straw	84.7	84.2	84.9	81.4	92.8	85.1	88.2	75.1	84.6	96.4	84.3	75.3	84.4	6.08
E^* for maize stalk	129	122	145	118	129	136	128	131	142	145	126	133	132	8.63
E^* for wheat stalk	26.9	26.9	31.5	27.1	25.8	26.7	26.5	25.6	28.5	—	—	—	27.3	1.79

Note: E^* is the emission factor of nitrous oxide in mg/kg or g/t; \bar{x} is the average of n runs; σ_{n-1} is the standard deviation

The total nitrogen content in the air-dried biomass samples was determined by a Kaiser Nitrogen Analyzer. It equals to 0.88% for rice straws, 0.98% for maize leaves and 0.78% for maize stalks, respectively. In order to compare our results with the values in the literature for open combustion, which were calculated on a dry basis, our data on the total nitrogen content in the biomass have been converted to the dry basis (dried at 105°C): 0.92% for rice straw, 1.04% for maize leaves and 0.82% for maize stalks.

Based on the total nitrogen in dry biomass, the ratios of nitrogen in nitrous oxide to the total nitrogen in biomass are listed in Table 5.

Table 5 The ratio of nitrogen in nitrous oxide to the total nitrogen in dry biomass, R

Number of runs	1	2	3	4	5	6	7	8	9	10	11	12	\bar{n}
R for rice straw, %	0.59	0.58	0.59	0.56	0.64	0.59	0.61	0.52	0.58	0.67	0.58	0.52	0.59
R for maize stalk, %	0.85	0.81	0.96	0.78	0.85	0.90	0.85	0.87	0.94	0.96	0.83	0.88	0.87

4 Discussions

4.1 Effect of sampling time

The air temperature in the combustion chamber rises and then drops during a

run. Experiments showed that the emission factor values determined during temperature-rising stage are larger than those during temperature-declining stage. Obviously, the results obtained during temperature-declining stage are too low. So the operation of sampling must be completed before the chamber temperature begins to decrease, i. e., within one minute after fire extinction. And the correction of gas volume due to temperature variation has been taken into consideration.

4.2 Effect of sample storage time

Cofer (Cofer, 1991) reported that if a gas sample is stored in a sampling bag over 4–8 hours, heterogeneous chemical reactions would lead to an increase in nitrous oxide concentration. In our experiments, all samples were analyzed within 0.5 hour after their collection. That is to say, the time of storage was less than 1/2 hour.

4.3 Oxygen concentration in the combustion chamber

The weight of a biomass sample to be burnt in the combustion chamber should be compatible with the amount of oxygen available in the chamber. Since the air volume in the combustion chamber is 321 L, the optimal biomass sample weight is 5g. The oxygen concentration after fire extinction in the chamber would be still in the range of 18%.

4.4 Comparison of experimental results with those in references

According to Jurgen (Jurgen, 1990), dry biomass was burned in a combustion facility simulating open fires. The ratio of nitrogen in nitrous oxide to the total nitrogen in biomass was determined to be $0.77 \pm 0.21\%$ by the flow sampling method. In this report, rice straws and maize stalks were burned in an enclosed burning apparatus and the ratio of nitrogen in nitrous oxide to the total nitrogen in biomass was determined to be 0.59% for rice straws, and 0.87% for maize stalks. They fall in the range of Jurgen's results $0.77 \pm 0.21\%$. Jurgen (Jurgen, 1990) also showed that the ratio of nitrogen in ash to the total nitrogen in biomass was $9.89 \pm 0.95\%$. In the present paper, the ratio of nitrogen in ash to the total nitrogen in biomass was 9.89%, which coincides very well with Jurgen's value.

4.5 Distribution of nitrous oxide emission from biomass burning in China mainland

On the basis of statistics on crop production and cropped area in all regions in China mainland and according to the relationship between seed-weight or spike-weight and stem-weight, the weights of stalks and leaves corresponding to the grain yield were obtained. Multiplication of crop residue weight by the nitrous oxide emission factors gives the annual emission of nitrous oxide from rice straw, maize stalk, and wheat stalk burning in China.

The ratio of dry weight of maize stems and leaves to the grain weight is equal to 1.27, the ratio of dry weight of rice stalks to the spike weight is 1.35, while that of the dry weight of wheat stalks to the spike weight is 0.82. Based on a random sampling survey, the fraction of crop residues burnt is taken to be 0.70. The distribution of annual emission of nitrous oxide from biomass burning in China mainland is shown in Fig.1 as an $1^{\circ} \times 1^{\circ}$ grid map.

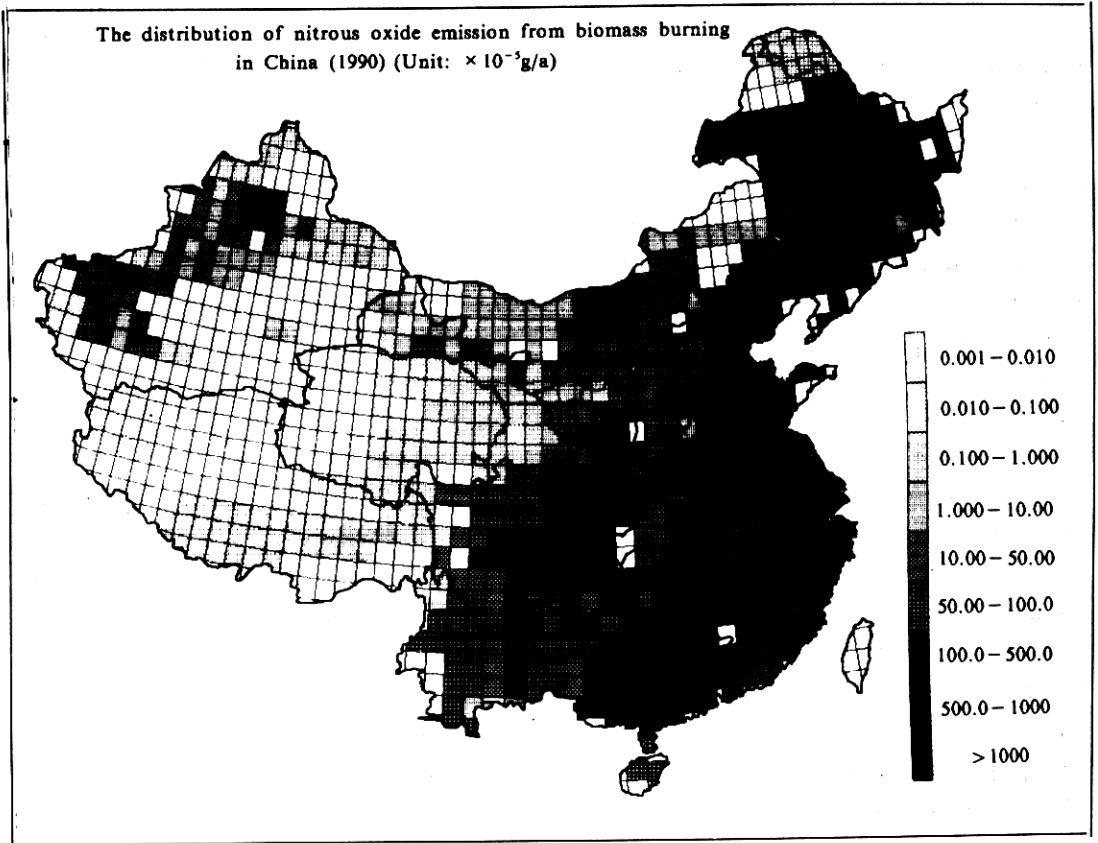


Fig.1 The distribution of nitrous oxide emission biomass burning in China mainland (1990, $\times 10^5$ g/a).

5 Conclusions

The emission factors of nitrous oxide from biomass burning were determined:

84.4±6.08g/t for rice straws, 132±8.63g/t for maize stalks, and 27.3±1.79g/t for wheat stalks, respectively. The annual emission of nitrous oxide in 1990 from biomass burning was estimated. The distribution of nitrous oxide emission from biomass burning was shown in an 1°×1° grid map.

References

- Cofer WR. Nature, 1991; 349:689
Hisafumi Muramatsu. Bull Chem Soc Jpn. 1982; 55(1): 117
Levine JS. Conference summary in Chapman conference on global biomass burning, NASA Langley Research Center, Hampton, Virginia, August 16, 1990
Jurgen ML. Nature, 1990; 346:552
Matson PA. J Geophys Res, 1990; 95(D10): 16
Takahisa Yokoyama. Environ Sci Technol, 1991; 25(2): 347