

Nobuhisa Watanabe · Noboru Tanikawa · Tomo Oikawa
Saburo Inoue · Johji Fukuyama

Improved quartz furnace method for chlorine and sulfur determination in municipal solid waste

Received: March 20, 2002 / Accepted: October 13, 2002

Abstract A method of determining the chlorine (Cl) and sulfur (S) in municipal solid waste (MSW) was studied. The quartz furnace method was improved in two ways: recovery from ash by hot extraction with dilute nitric acid, and avoidance of the volatilization of alkali (earth) metal chlorides by setting the sample combustion temperature at 600°C. In a comparison with the bomb method, using nine sets of kitchen garbage and waste plastics, the bomb method yielded a 15%–25% lower value than the improved quartz furnace method. Combustion in the bomb was frequently incomplete, resulting in recovery losses of Cl and S. The average kitchen garbage involved 5.2 mg Cl/g, of which at least 24.1% would be converted to HCl. Plastics contained 23 mg Cl/g generating 88.1% HCl on average. In the same way, kitchen garbage contained 3.0 mg S/g, generating 52.3% SO_x, whereas plastics contained 1.1 mg S/g with 55.1% SO_x formation.

Key words Chlorine · Sulfur · Quartz furnace · Bomb · MSW · Plastics · Kitchen garbage

Introduction

Chlorine (Cl) and sulfur (S) are important ingredients in municipal solid waste (MSW) from the viewpoints of treatment and recycling. When combusted, Cl and S in fuel are significantly converted to the acid pollutants HCl and SO_x.

However, the concentrations of Cl and S in the combustion system is of interest in view of the formation of dioxins. It is now agreed that not only Cl from plastics, but also Cl from other components can be a source of chlorinated dioxins,^{1–3} and hence Cl from various sources is now of great common interest. Sulfur is also viewed as a key element in dioxins formation. It has been demonstrated that the reductive activity of sulfur dioxide (SO₂) in a chemical reaction in a fire could suppress the chlorinating activity, resulting in a decrease in halogenated dioxins.^{4,5}

The other current issue regarding Cl and S in MSW is related to material recycling. They are often undesirable ingredients, interfering with the recycling processes, e.g. when used for cement production.⁶

In 1999, the Japanese Industrial Standard (JIS) Z 7302–6, a method of determining the Cl in refuse-derived fuel, was issued. This involved both the quartz furnace method and the bomb method.⁷ The same procedure was also proposed as a preliminary method for S.⁸ In the quartz furnace method, the sample is combusted in a quartz furnace to generate HCl and SO_x, which are absorbed to an aquatic solution of hydrogen peroxide (H₂O₂) and determined as Cl[–] and SO₄^{2–}. In the bomb method, the sample is combusted in a closed bomb, the inner materials from which are collected and the Cl[–] and SO₄^{2–} determined. Thus, the bomb method determines total Cl and S, while the quartz furnace method accounts for combustible Cl and S only. As a portion of the Cl and S remains in the ash in the quartz furnace method, the sum of the Cl and S from the absorber and from the ash should be the same as the value obtained by the bomb method. However, these values are often inconsistent, and increasing the sample combustion temperature results in a decrease of “total Cl” by the quartz furnace method.

In this paper, the above phenomena are first demonstrated, illustrating the deposition of Cl to the inner surface of the quartz tube. Then an improved quartz furnace method is proposed, which recovers Cl and S from the ash and avoids the deposition of Cl onto the quartz surface. At the same time, the bomb method was also applied comparatively, revealing that it would give a relatively lower value than the improved quartz furnace method owing to incom-

N. Watanabe (✉) · S. Inoue · J. Fukuyama
Environment Preservation Research Center, Kyoto University,
Yoshidahonmachi, Sakyo-Ku, Kyoto 606-8501, Japan
Tel. +81-75-753-7712; Fax +81-75-753-7713
e-mail: watakama@eprc.kyoto-u.ac.jp

N. Tanikawa
Division of Environment Resource, Graduate School of Engineering,
Hokkaido University, Sapporo, Japan

T. Oikawa
Tokyo Metropolitan Research Institute for Environmental, Tokyo,
Japan

plete combustion in the bomb, which frequently occurred with MSW samples.

Experimental

Sample preparation

MSW samples were collected from the reservoirs of municipal waste incinerators in Osaka city. The sample collection procedure was as follows. One tonne of crane – grabbed MSW was homogeneously reduced to ca. 20kg and dried at 85°C for 3 days. It was then hand-sorted into six combustible fractions: kitchen garbage; paper; textiles; wood and leaves; plastics, rubber and leather (here shortened to “plastics”); and small tips, and four incombustible fractions: glass; stone and ceramics; ferrous steel; and nonferrous metal. Every combustible fraction was crushed to pass a 1-mm screen.

For the quartz furnace rinse experiment, we used kitchen garbage and plastics collected from one of the Osaka city controlled incinerators, the Nishiyodo facilities, on April 8, 1998. The kitchen garbage was expected to contain much more inorganic Cl than organic Cl, while the plastics would show the opposite.

For the comparative study of the improved quartz furnace and the bomb method, we used nine samples from different facilities in Osaka city, collected during September and October 2000.

Quartz furnace rinse experiment

The quartz furnace and the procedure used are shown in Fig. 1. The apparatus is identical to JIS Z 7302-6.⁷ An empty quartz tube, 18mm inner diameter and 590mm in length, was used as the furnace. A length of 200mm at one end was kept at 900°C by a fixed heater, and a moving heater, which operated automatically, heated the rest of the tube. The sample was mounted on a quartz boat and placed to the side of the fixed heater. The moving heater started from the rear of the quartz vessel and moved until it reached the fixed heater, taking 9 min to move, and remaining in contact with the fixed heater for 8 min.

The temperature of the moving heater was set at 600°, 700°, 800°, and 850°C. An air-flow of 1 l/min was drawn into the tube as the oxidation gas. This was introduced to the absorbing solution (25 + 25 ml of 1% H₂O₂) in two steps. The weight of the sample was 0.4 g for kitchen garbage and 0.2 g for plastics. After sample combustion, the boat was extracted with distilled water in a test tube. The inner surface of the quartz tube was then rinsed with distilled water. Finally, three fractions were obtained, i.e., the boat, the furnace, and the absorber fractions. All experiments were carried out in duplicate.

Improved quartz furnace method

In order to enhance the gas combustion, a quartz tube containing silica chips and sited at the fixed heater was used

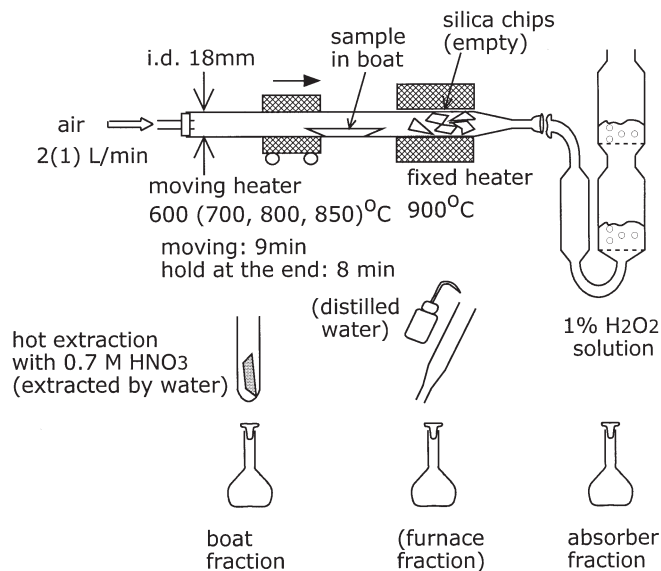


Fig. 1. Quartz furnace method: apparatus and procedure. The conditions and parameters in parentheses are for the quartz furnace rinse experiment

(Fig. 1). The temperature of the moving heater was adjusted to 600°C. The oxidation gas was air at 2 l/min. The weight of the sample was 0.5 g for kitchen garbage and 0.2 g for plastics. The absorbing solution was diluted to 100 ml for kitchen garbage and 250 ml for plastics. The ash on the boat was extracted with 0.7 M HNO₃ (prepared by a 20-fold dilution of 14 M HNO₃), at boiling point, in a test tube inserted into an aluminum heat block for 0.5 h. The amount of 0.7 M HNO₃ used for kitchen garbage was 5 ml diluted to 250 ml, while 2 ml 0.7 M HNO₃ diluted to 100 ml was used for plastics. Consequently, two fractions were collected, i.e., the boat and the absorber fractions. All measurements were performed in duplicate.

Ion chromatography

The concentrations of Cl and SO₄²⁻ in the sample solutions were determined with an ion chromatograph Dionex QIC system, the conditions of which were as follows: column, IonPac AS4A; eluent, 1.7 mM NaHCO₃–1.8 mM Na₂CO₃; suppressor regenerant, 25 mM H₂SO₄; detector, electrical conductivity.

Proximate analysis and contents of Na, K, Ca, and Mg

The MSW sample was weighed on a quartz boat, and placed in the quartz furnace. The sample was dried at 100°C overnight, followed by combustion in the quartz furnace at 600°C for 2 h. By measuring the weight difference, the proximate composition was obtained. The ash in the quartz boat was extracted in 5 ml 0.7 M HNO₃ in a test tube for 2 h and diluted to 100 ml, which underwent ICP–OES analysis for the determination of Na, K, Ca, and Mg.

Bomb method

A bomb of 300 ml capacity, as illustrated in Fig. 2, was used. The sample (0.5 g for kitchen garbage, 0.3 g for plastics) was wrapped in a paper capsule and connected to the electrodes with nickel wire. The absorbing solution was 5 ml 1% H_2O_2 , which was placed at the bottom of the bomb. The bomb was closed, and then 30 atmospheres of oxygen was introduced. After electrical ignition had induced sample combustion, the bomb was kept closed for 0.5 h. The inner surface was then rinsed with distilled water, which was analyzed for Cl^- and SO_4^{2-} . Duplicate measurements were conducted for kitchen garbage, whereas measurements for plastics were conducted in triplicate because considerable data variation was found in plastics.

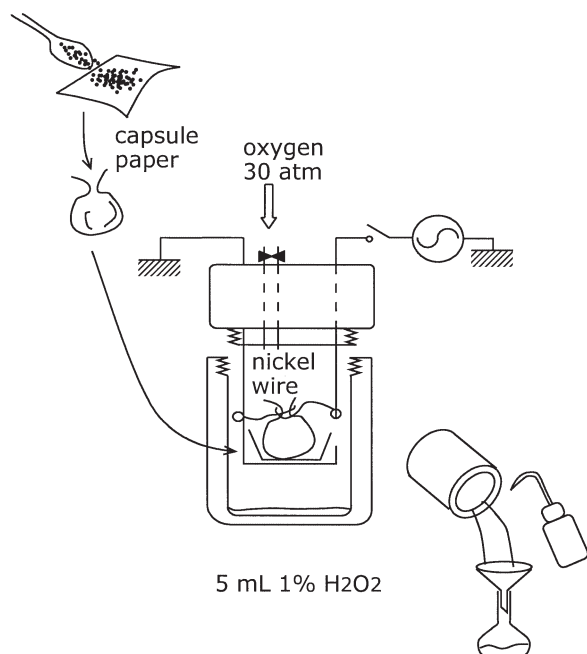


Fig. 2. Bomb method

Results and discussion

Quartz furnace rinse experiment

All duplicate data for the Cl distribution in the three fractions (boat, furnace, and absorber) at each temperature of the moving heater are given in Table 1. Figures 3 and 4 show the results graphically using the average values of kitchen garbage and plastics, respectively. First, as the temperature was set higher, the boat fraction clearly decreased, while the furnace and the absorber fractions increased. Second, the total Cl recovered from kitchen garbage decreased with increasing temperatures.

The Cl compound which was volatilized from the boat and remained in the quartz furnace was thought to be alkali (earth) metal chlorides. It could be considered that the volatilized alkali (earth) metal chlorides were deposited onto the quartz surface in the furnace, which was partially recovered by the distilled water rinse. The saturated vapour pressures of NaCl , MgCl_2 , KCl , and CaCl_2 are shown in Fig. 5. Those alkali (earth) metal chlorides have a saturated vapour pressure as high as 0.001 atm at 800°C , which makes

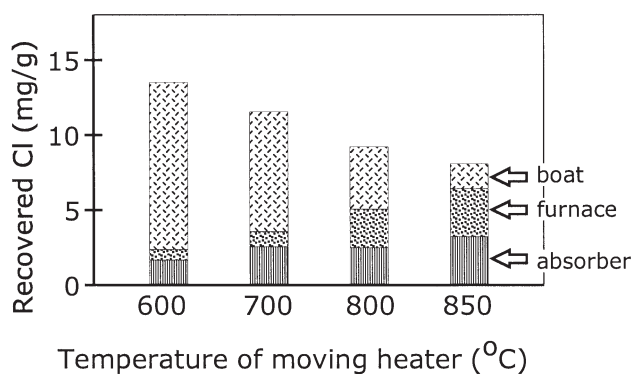


Fig. 3. Cl recovered from kitchen garbage in the quartz furnace rinse experiment

Table 1. The distribution of Cl to the boat, furnace, and absorber fractions in the quartz furnace rinse experiment

Temperature (°C)	Kitchen garbage			Plastics		
	Boat	Furnace	Absorber	Boat	Furnace	Absorber
600						
Run 1	12.5	0.7	1.7	11.9	0.1	9.6
Run 2	9.7	0.8	1.6	9.0	0.2	8.7
700						
Run 1	7.6	1.2	2.5	10.2	0.7	9.6
Run 2	8.4	0.9	2.6	9.3	0.8	8.6
800						
Run 1	5.8	2.1	2.4	2.2	2.6	13.9
Run 2	2.5	3.1	2.6	2.8	2.6	16.1
850						
Run 1	2.3	2.9	2.5	1.5	3.0	16.5
Run 2	1.0	3.5	3.9	0.9	1.9	15.9

Units mg Cl/g

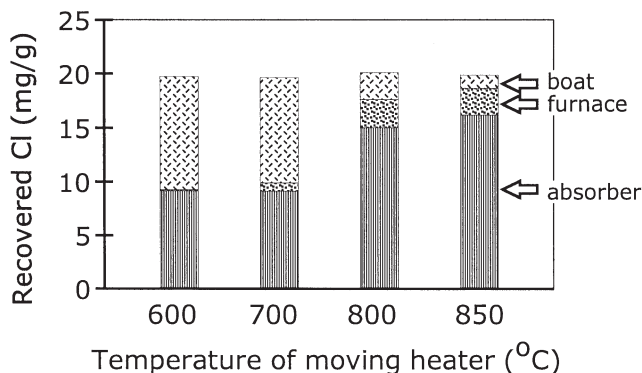


Fig. 4. Cl recovered from plastics in the quartz furnace rinse experiment

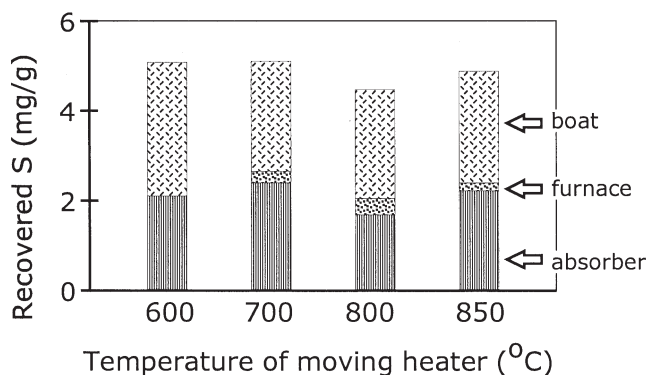


Fig. 6. S recovered from kitchen garbage in the quartz furnace rinse experiment

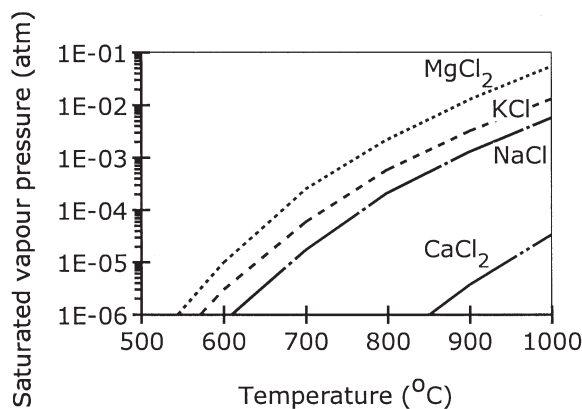


Fig. 5. Saturated vapour pressure of alkali (earth) metal chlorides

volatilization feasible. Yasuhara et al.³ observed a weight loss of NaCl due to volatilization at 800°C, suggesting the effect of inorganic Cl on dioxins formation. KCl condensation was also observed along the flue gas duct in the chlorine bypass of a cement kiln.⁶ The Na, K, Ca, and Mg contents in the used samples are given in Table 2. The presence of K (1.6 and 0.59 mg/g for kitchen garbage and plastics, respectively) and Na (8.5 and 8.3 mg/g, respectively) were sufficient to convey Cl to the quartz furnace (3.5 and 3.0 mg/g maximum, respectively).

Another problem was the decrease in the total Cl recovered from kitchen garbage with increasing temperatures. That was supposedly due to sintering, i.e., the formation of barely soluble compounds by matrix elements. It is empirically well known that quartz glass loses its transparency after several uses at a temperature as high as 900°C, which demonstrates that some chemical reaction between sample matrices takes place. It is assumed that Cl was involved in such a reaction, or was confined in the barely soluble compounds.

The results for S are given in Table 3, from which Figs. 6 and 7 are obtained. Little distribution to the quartz furnace fraction, as well as no effect from the temperature of the moving heater, was observed in the range 600–850°C.

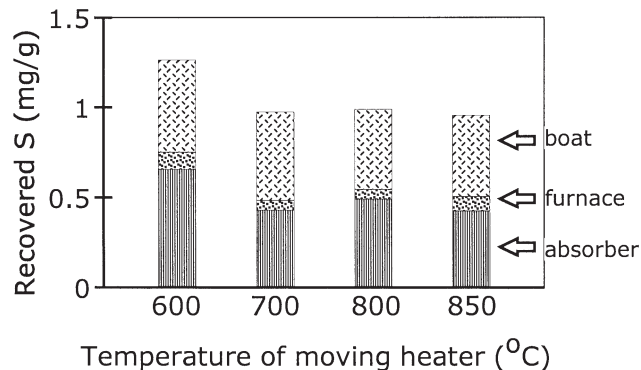


Fig. 7. S recovered from plastics in the quartz furnace rinse experiment

Table 2. Content of alkali (earth) metals in samples in the quartz furnace rinse experiment

	Moisture	Ash	Na	Mg	K	Ca
	(%)		(mg/g)			
Kitchen garbage	5.6	13.8	8.5	1.7	1.6	50
Plastics	3.0	9.2	8.3	1.3	0.59	7.7

After these experiments, an attempt was made to improve the quartz furnace method. The temperature of the moving heater was set at 600°C in order to minimize the volatilization of alkali (earth) metal chlorides, and the extraction in the vessel was performed in a more aggressive condition, i.e., hot extraction with 0.7 M HNO₃. This condition can keep the extraction acidity below pH 2, and it does not interfere with the ion chromatograph.

Application of an improved quartz furnace and bomb method to various samples

All the results for Cl contents in kitchen garbage and plastics are presented in Table 4, from which comparative descriptions are illustrated in Figs. 8 and 9.

Table 3. The distribution of S to the vessel, furnace, and absorber fractions in the quartz furnace rinse experiment

Temperature (°C)	Kitchen garbage			Plastics		
	Boat	Furnace	Absorber	Boat	Furnace	Absorber
600						
Run 1	3.47	0.00	1.96	0.54	0.08	0.71
Run 2	2.48	0.00	2.25	0.49	0.11	0.60
700						
Run 1	2.59	0.00	2.36	0.51	0.06	0.36
Run 2	2.32	0.51	2.43	0.47	0.05	0.50
800						
Run 1	2.69	0.00	2.07	0.44	0.06	0.49
Run 2	2.16	0.73	1.30	0.45	0.05	0.49
850						
Run 1	3.11	0.18	2.17	0.46	0.10	0.38
Run 2	1.88	0.16	2.27	0.44	0.06	0.47

Units mg S/g

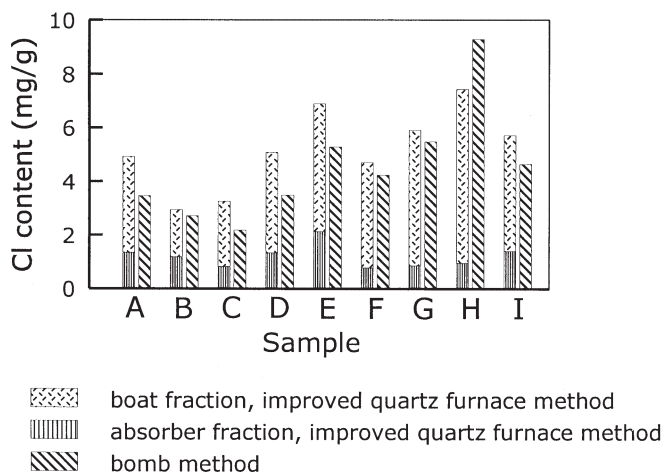
Table 4. Chlorine content in MSW samples measured by the improved quartz furnace method and the bomb method

Sample	Kitchen garbage			Bomb method	Plastics			Bomb method
	Improved quartz furnace method				Improved quartz furnace method			
	Boat	Absorber	Total		Boat	Absorber	Total	
A								
Run 1	3.9	1.3	5.3	3.6	0.5	28.8	29.2	18.8
Run 2	3.3	1.3	4.6	3.3	0.6	23.9	24.5	24.2
Run 3								13.8
B								
Run 1	1.8	1.2	3.0	2.6	0.5	12.9	13.4	9.0
Run 2	1.7	1.1	2.9	2.8	0.5	12.6	13.1	7.5
Run 3								12.0
C								
Run 1	2.2	0.8	3.1	2.0	2.4	6.3	8.7	9.4
Run 2	2.7	0.8	3.5	2.3	1.9	4.5	6.3	6.7
Run 3								11.2
D								
Run 1	3.6	1.2	4.9	3.5	0.7	4.5	5.2	7.5
Run 2	3.9	1.4	5.3	3.5	0.7	5.1	5.8	7.9
Run 3								6.8
E								
Run 1	4.1	2.0	6.1	5.5	4.0	20.2	24.2	19.6
Run 2	5.5	2.3	7.7	5.1	3.0	19.1	22.1	15.5
Run 3								18.6
F								
Run 1	4.1	0.8	4.9	4.2	0.6	26.7	27.4	17.4
Run 2	3.7	0.7	4.5	4.3	0.7	22.0	22.7	18.8
Run 3								23.9
G								
Run 1	4.8	0.7	5.6	5.6	3.5	29.9	33.4	30.0
Run 2	5.3	1.0	6.3	5.4	3.4	30.6	34.0	23.7
Run 3								16.6
H								
Run 1	6.2	0.9	7.1	8.5	5.1	20.0	25.1	21.0
Run 2	6.8	1.0	7.8	10.0	4.6	18.1	22.8	16.6
Run 3								8.8
I								
Run 1	4.3	1.5	5.8	5.0	5.7	37.2	42.9	32.6
Run 2	4.3	1.3	5.6	4.3	5.4	39.0	44.4	34.0
Run 3								32.2

Units mg Cl/g

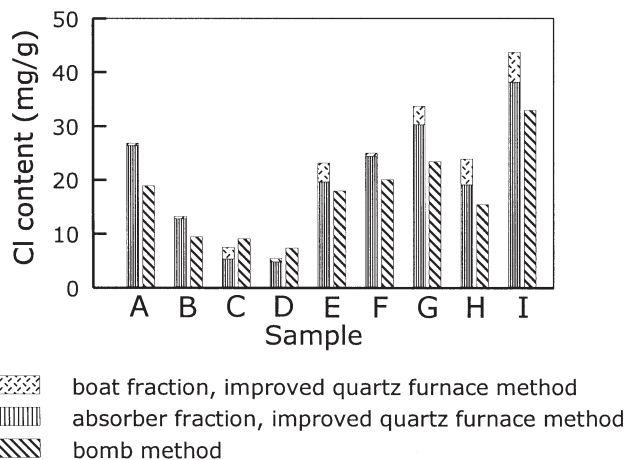
Table 5. Summary of a comparative study of the improved quartz furnace method and the bomb method

	Cl		S	
	Kitchen garbage	Plastics	Kitchen garbage	Plastics
(Bomb method)/(Improved quartz furnace method) (%)	84.9 ± 17.0	85.0 ± 23.4	77.3 ± 7.4	85.7 ± 18.2
Distribution to absorber fraction in improved quartz furnace method (%)	24.1 ± 8.1	88.1 ± 8.2	52.3 ± 9.4	55.1 ± 17.3
Average total concentration by improved quartz furnace method (mg/g)	5.2 ± 1.4	23 ± 12	3.0 ± 0.7	1.1 ± 1.1

**Fig. 8.** Comparison of the Cl content in the kitchen garbage measured by the improved quartz furnace method and the bomb method

The results of the comparative study are summarized in Table 5. The values obtained by the bomb method were generally 15%–25% lower than those by the improved quartz furnace method. The reason was found to be the difficulty of complete combustion in the bomb, which was particularly observed for plastics. In addition, the poor reproducibility for Cl in plastics gave further evidence. In research into Br determination in plastics,⁹ the analytical values also suffered from incomplete combustion in the bomb method. The bomb method was initially developed for fuel analysis,¹⁰ where complete combustion is achieved, but this does not hold true for MSW samples. As well as incomplete combustion, another factor interfering in Cl and S recovery was suspected: adsorption or deposition to ash. A feasible S deposition is CaSO_4 , which is barely soluble in neutral water.

The potential for acid pollution through combustion can be assessed by the distribution to the absorber fraction in the improved quartz furnace method. For kitchen garbage, $24.1\% \pm 8.1\%$ of a total of $5.2 \pm 1.4 \text{ mg Cl/g}$ would be converted to HCl during combustion. In the same way, HCl from plastics was assessed to be $23 \text{ mg Cl/g} \times (88.1/100)$ on average. However, since the distribution rate increases with the combustion temperature, the value achieved at 600°C could be considered as the lower boundary of HCl generation.

**Fig. 9.** Comparison of the Cl content in the plastics measured by the improved quartz furnace method and the bomb method

In the present study, the chlorine in plastics was as low as half of the previous data collected during the 1970s.¹¹ The reason is supposedly the exclusion of polyvinyl chloride (PVC) from all commodities.

The duplicate and triplicate results for S are given in Table 6, with graphical depiction in Figs. 10 and 11. As for Cl, the S content from the bomb method was about 15% lower than that of the improved quartz furnace method. On average, kitchen garbage contained 3.0 mg S/g , generating 52.3% SO_x , whereas plastics contained 1.1 mg S/g with 55.1% SO_x formation.

Alternative methods for MSW analysis

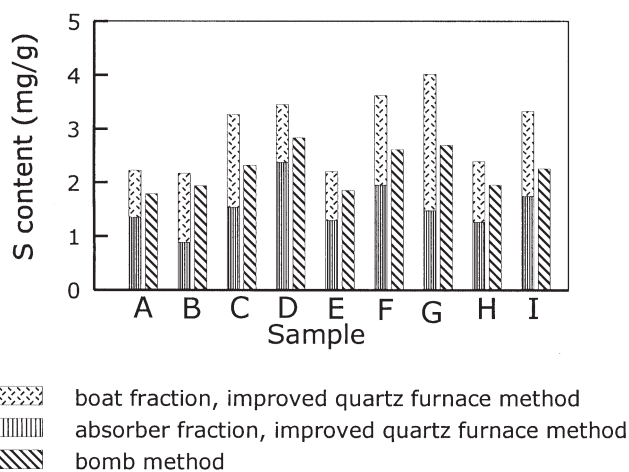
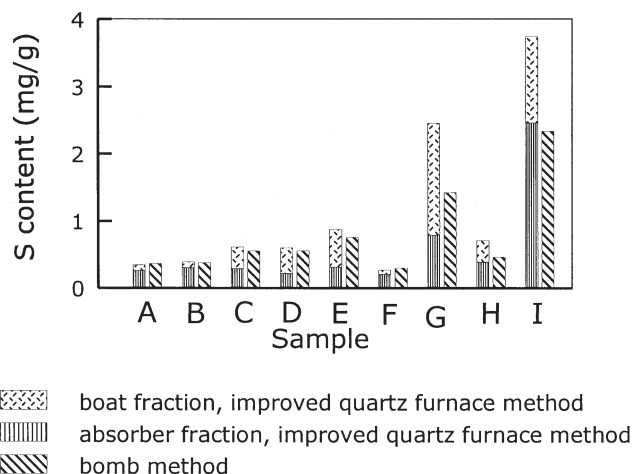
As discussed above, the improved quartz furnace method could recover more Cl and S than the bomb method, and it could be indicative of the potential of acidic pollution through combustion. In the present study, the improved quartz furnace method was found to be superior to the bomb method for MSW analysis. However, some improvement to the bomb method could also be possible, e.g., reducing the size of the sample, or the addition of a combustion-promoting reagent to the sample.

The Eschka method, the other alternative authorized method for Cl and S determination for fuel analysis,¹⁰ would

Table 6. Sulfur content in MSW samples measured by the improved quartz furnace method and the bomb method

Sample	Kitchen garbage				Plastics			
	Improved quartz furnace method			Bomb method	Improved quartz furnace method			Bomb method
	Boat	Absorber	Total		Boat	Absorber	Total	
A								
Run 1	1.0	1.3	2.3	1.8	0.10	0.28	0.38	0.46
Run 2	0.8	1.4	2.1	1.8	0.08	0.24	0.32	0.36
Run 3								0.28
B								
Run 1	1.3	0.9	2.2	2.0	0.08	0.32	0.41	0.47
Run 2	1.2	0.9	2.1	1.9	0.10	0.28	0.38	0.24
Run 3								0.42
C								
Run 1	1.6	1.5	3.1	2.3	0.32	0.28	0.60	0.63
Run 2	1.9	1.6	3.5	2.3	0.34	0.29	0.63	0.50
Run 3								0.53
D								
Run 1	1.1	2.3	3.4	2.8	0.36	0.22	0.58	0.62
Run 2	1.1	2.5	3.5	2.9	0.41	0.21	0.62	0.51
Run 3								0.54
E								
Run 1	0.8	1.2	2.0	1.8	0.50	0.27	0.78	0.81
Run 2	1.1	1.4	2.4	1.9	0.63	0.34	0.97	0.71
Run 3								0.76
F								
Run 1	1.8	2.0	3.7	2.5	0.07	0.21	0.28	0.38
Run 2	1.6	1.9	3.5	2.7	0.07	0.19	0.26	0.21
Run 3								0.31
G								
Run 1	2.5	1.2	3.7	2.8	1.58	0.80	2.38	1.42
Run 2	2.6	1.7	4.3	2.6	1.74	0.78	2.53	1.61
Run 3								1.24
H								
Run 1	1.0	1.2	2.3	1.9	0.30	0.40	0.71	0.50
Run 2	1.2	1.3	2.5	2.0	0.34	0.37	0.72	0.58
Run 3								0.31
I								
Run 1	1.6	1.8	3.4	2.2	1.25	2.32	3.57	2.36
Run 2	1.6	1.7	3.2	2.3	1.32	2.59	3.91	2.41
Run 3								2.24

Units mg S/g

**Fig. 10.** Comparison of the S content in the kitchen garbage measured by the improved quartz furnace method and the bomb method**Fig. 11.** Comparison of the S content in the plastics measured by the improved quartz furnace method and the bomb method

also be a practical method for MSW. In this method, the sample is mixed with an Eschka reagent (e.g., a mixture of MgO and Na₂CO₃) and is combusted in a crucible, followed by Cl and S determination by acid-alkali titration. However, we have not tested this method in the present comparative study, because the high salt content in the digested solution interfered with the ion chromatograph determination.

The energy-dispersive X-ray fluorescence method (EDXRF) is currently listed in JIS K 2541¹² as a reference method for the determination of S in crude oil and petroleum products. Although its application for Cl in MSW is still not authorized, it could be very practical depending on the development of the instrument. Nevertheless, chemical methods such as the improved quartz furnace method will be also important because they are indicative of acidic pollution through combustion.

Conclusions

The quartz furnace method and the bomb method for the determination of chlorine (Cl) and sulfur (S) in MSW were studied. In the quartz furnace method, the distributions of Cl and S to boat, quartz furnace, and absorber fractions were investigated. Significant distributions to the ash in the boat and a considerable deposition onto the inner surface of the quartz furnace were observed. The mechanism of deposition of Cl in the quartz furnace was thought to be the volatilization of alkali (earth) metal chlorides, which was considerable at the high temperature of the sample combustion. Based on these observations, the quartz furnace method was improved in two ways: hot extraction of the ash in the boat with 0.7M HNO₃ to recover the Cl and S in the ash, and combustion of the sample at 600°C to minimize the deposition to the quartz furnace.

A comparative study of the improved quartz furnace and the bomb method using kitchen garbage and plastics was conducted. Total Cl and S obtained by the bomb method were 15%–25% lower than those of the improved quartz furnace method. The lower recovery in the bomb method was mainly due to incomplete combustion in the bomb.

The absorber fraction in the improved quartz furnace method provided an estimate of the acidic pollution gener-

ation during combustion. Kitchen garbage contained 5.2 mg Cl/g on average, of which 24.1% would be converted to HCl. Plastics contained 23 mg Cl/g on average, 88.1% of which was distributed to the absorber. Kitchen garbage also contained 3.0 mg S/g, generating 52.3% SO_x, whereas plastics contained 1.1 mg S/g, with 55.1% SO_x formation.

Acknowledgment This work was financially supported by the Steel Industry Foundation for the Advancement of Environmental Protection Technology (SEPT).

References

1. Rigo GH, Chandler AJ (1998) Is there a strong dioxin:chlorine link in commercial scale systems? *Chemosphere* 37:2031–2046
2. Gullett BK, Sarofim AF, Smith KA, Procaccini C (2000) The role of chlorine in dioxin formation. *Process Saf Environ Prot* 78(B1):47–52
3. Yasuhara A, Katami T, Okuda T, Ohno N, Shibamoto T (2001) Formation of dioxins during the combustion of newspapers in the presence of sodium chloride and poly(vinyl) chloride. *Environ Sci Technol* 35:1373–1378
4. Raghunathan K, Gullett BK (1996) Role of sulfur in reducing PCDD and PCDF formation. *Environ Sci Technol* 30:1827–1834
5. Tuppurainen K, Halonen I, Ruokojärvi P, Tarhanen J, Ruuskanen J (1998) Formation of PCDDs and PCDFs in municipal waste incineration and its inhibition mechanisms: a review. *Chemosphere* 36:1493–1511
6. Ueno N, Uchida H, Harada H, Yoshida A, Hirose T (1998) Stable kiln operation and effective recycling of waste achieved by the chlorine bypass system (in Japanese). *Proceedings of the Cement Manufacturing Technology Symposium No. 55*, pp 24–31
7. Japanese Industrial Standards Committee (1999) Densified refuse-derived fuel. Part 6. Test method for total chlorine content. *JIS Z 7302-6*
8. Japanese Industrial Standards Committee (1999) Densified refuse-derived fuel. Test method for sulfur content. *TR Z 0012*
9. Tanikawa N, Oikawa T, Masuko T, Watanabe N (2001) Study on the determination of bromine in plastics from waste televisions. *Proceedings of the 10th Pacific Basin Conference on Hazardous Waste*, December 5–7, 2001, Okayama City, pp 257–260
10. Japanese Industrial Standards Committee (1994) Coal and coke. Methods for ultimate analysis. *JIS M 8813*
11. Kubota H, Uchida S, Tsubone S, Katayama S, Tsuchiya K, Suzuki T, Inukai S, Kamo H (1982) Volatile chlorine in municipal waste (in Japanese). *J Solid Liq Waste* 12:15–23
12. Japanese Industrial Standards Committee (1996) Crude oil and petroleum products. Determination of sulfur content. *JIS K 2541*