



ELSEVIER

Resources, Conservation and Recycling 20 (1997) 57-69

**resources,
conservation
and recycling**

Analysis of waste for combustion: the case of Osaka City, Japan

Nobuhisa Watanabe *, Hisao Ito

*Osaka City Institute of Public Health and Environmental Sciences, 8-34, Tojo-cho, Tennoji-ku,
Osaka City, 543, Japan*

Received 6 November 1996; received in revised form 5 December 1996; accepted 27 December 1996

Abstract

An analysis of the composition of waste for combustion is presented. The experimental protocol adopted for this study is the one used in Osaka city. Results over several years are given. A new format by which to describe physical, proximate and elemental composition as well as heat properties, is presented. Empirical values of the proximate composition of combustible components are given. These values are for composition estimates of some wastes. It is not clear exactly where and how much ash is generated in a municipal waste incinerator. Waste composition data enable the ash mass balance of an actual incinerator to be estimated. The methodology of elemental analysis is discussed. Chlorine and sulfur were determined by the tube combustion and bomb combustion methods. Comparisons suggest that the tube combustion method is preferable for pollution assessment. © 1997 Elsevier Science B.V.

Keywords: Waste analysis; Municipal waste; Proximate analysis; Elemental analysis; Ash mass balance

* Corresponding author. Tel: + 81-06-771-3354; Fax: + 81-06-772-0676.

1. Introduction

Understanding the composition of waste is essential for the planning, undertaking and evaluation of waste management. Waste can be analyzed in a number of ways. For example, in a recycling program, to establish a recycle rate and for progressive evaluations, waste analysis would be based on amounts of bottle, tin, paper, etc., while moisture, heat and elemental composition could be ignored. In contrast when waste is combusted, information regarding moisture, heat and elemental composition is indispensable. The type of waste analysis required depends on how flue gas is generated, how much ash remains and in what way pollution is anticipated. Waste composition has been discussed in a number of articles concerning waste management. Data are often based on a routine waste analysis program, but may be given as either dry base [1–3] or wet base [4,5], making comparisons difficult. Furthermore, the steps involved in waste analysis are often numerous, making accurate description impossible.

We have been carrying out routine waste analysis in Osaka city since the 1950s. This program is suitable for combustion treatment. Consequently much attention has been given to proximate analysis, heat analysis and elemental analysis. In this report we first suggest a versatile report format for waste composition, then describe analytical protocol, and lastly discuss ash mass balance in an incinerator, moisture calibration and methodology of elemental analysis.

2. Summary of waste management in Osaka City

Waste composition measurement is used for mass flow estimation. The methodology of such measurements varies from area to area. Therefore, we begin by providing an overall view of waste management in Osaka city (Fig. 1).

The total amount of waste in Osaka city is 2 088 600 tonne/year, comprising residential waste (34.9% of total), commercial waste (63.8%) and waste from public area cleansing (1.3%). Combustion is the major treatment for waste in Osaka city; 1 824 700 t/year, i.e. 87.4% of total waste is combusted then dumped. In Osaka city, the amount of combustion residue and incombustible waste (a portion of commercial and public cleansing waste) dumped is ca. 460 000 t/year (calculated under the assumption that residue is 25% of combusted waste) and 233 600 t/year, respectively. Bottles and tins are collected as 'recyclable waste'. Of the 29 900 t/year collected, 23 600 t/year (78.9%) are recycled. Steel alloy is also recycled. After being crushed and magnetically separated, 6700 t/year of steel is recycled in this way. As the population of Osaka City is ca. 2 600 000, the waste generation rate can be said to be 2200 g/day per person. However, if commercial waste is excluded, the figure becomes 770 g/day per person.

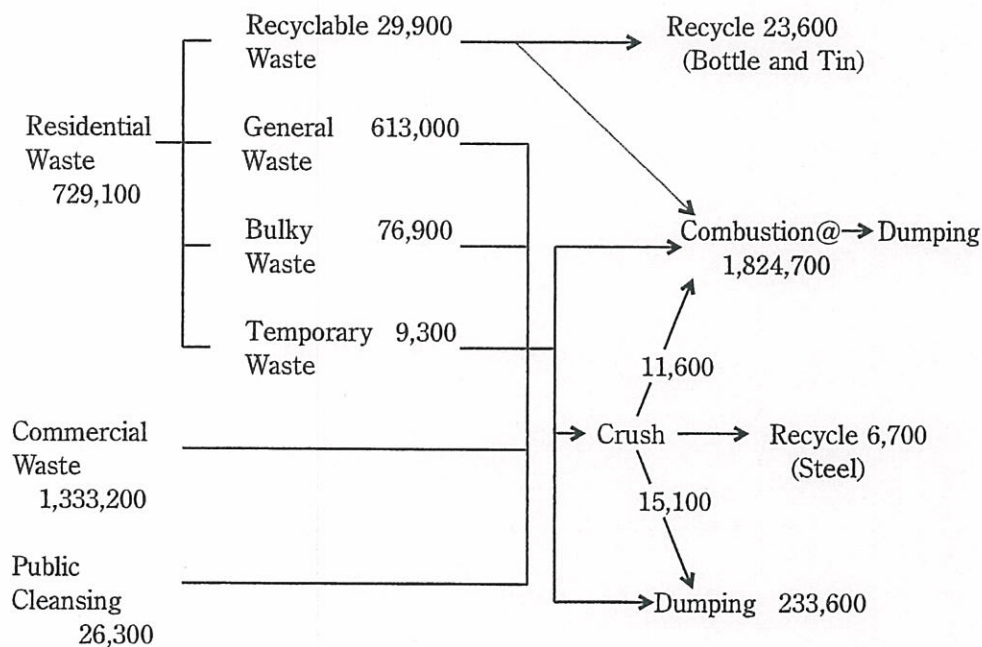
3. Composition of waste

Analytical samples were taken from the garbage pit of an incinerator. The sampling point is marked with an @ in Fig. 1. Waste composition is described in Fig. 2. The values shown in the table are from 32 sets of results gathered between 1992 and 1994. Ten sorting categories were used. Combustible components (six categories): (1) Kitchen Garbage; (2) Paper; (3) Textile; (4) Wood and leaves; (5) Plastic, rubber and leather; (6) Small tips (to pass a 5 mm screen). Incombustible components (four categories): (7) Glass; (8) Stone and ceramics; (9) Ferrous steel; (10) Non-ferrous alloy.

All components consist of ash (A(1)-A(10)), volatile matter (V(1)-V(10)) and moisture. Moisture was divided as follows: air dryable (Mair(1)-Mair(10)) and ultimately dryable (Mult(1)-Mult(10)). Volatile matter and ultimately dryable moisture of incombustible components are presumed to be zero (V(7)-V(10) = 0, Mult(7)-Mult(10) = 0). Total volatile matter, total ash and total moisture are the sum of V(i), A(i) and Mair(i) + Mult(i), respectively. In general, results of proximate analyses are given in percentages as below:

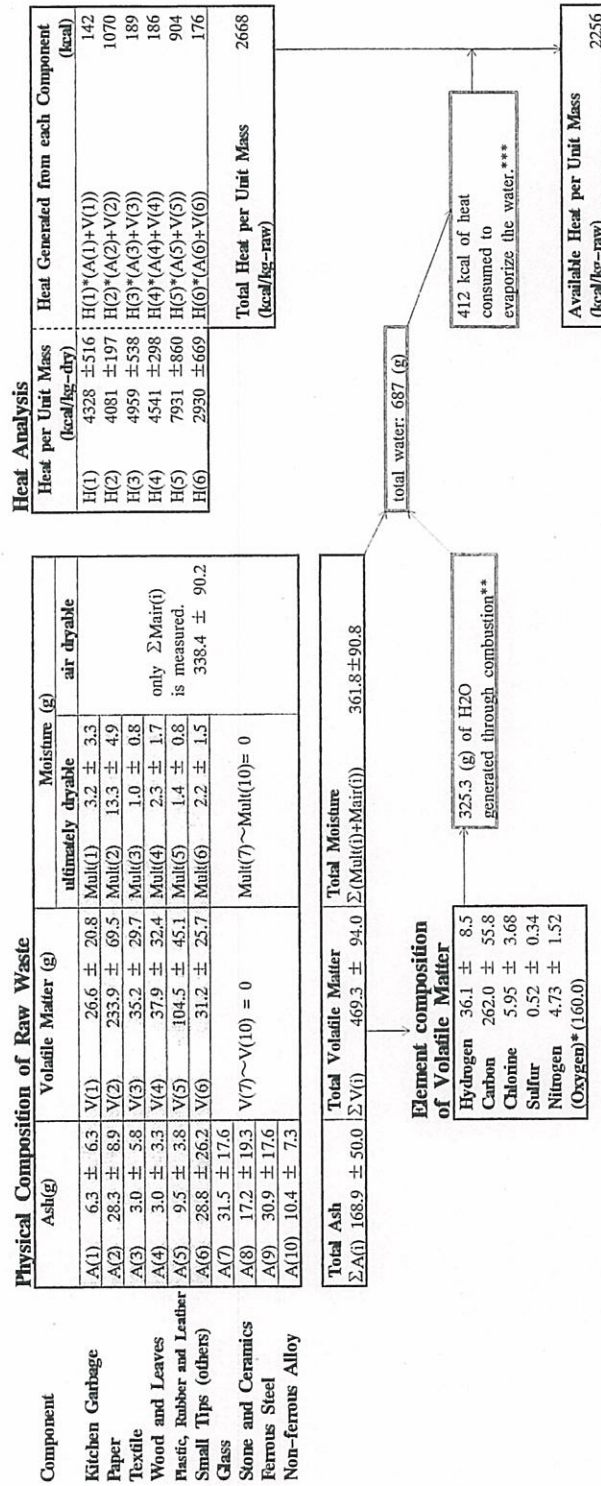
$$\text{Total Volatile Matter Content} = \sum V(i)/W \times 100(\%) \tag{1}$$

$$\text{Total Ash Content} = \sum A(i)/W \times 100(\%) \tag{2}$$



unit: tonne/year

Fig. 1. Summary of waste management of Osaka City.



* The remaining volatile matter is assumed to be oxygen
 ** 325.3(gH2O) = 36.14(gH) * 18(gH2O)/2(gH)
 *** 412(kcal) = 0.687(kgH2O) * 0.6(kcal/kgH2O)

All values are normalized to rend the total sample weight 1000(g).
 Data are from 32 sets gathered through 1992-1994.
 Hatched area represents "mixture of combustible components"

Fig. 2. Waste composition.

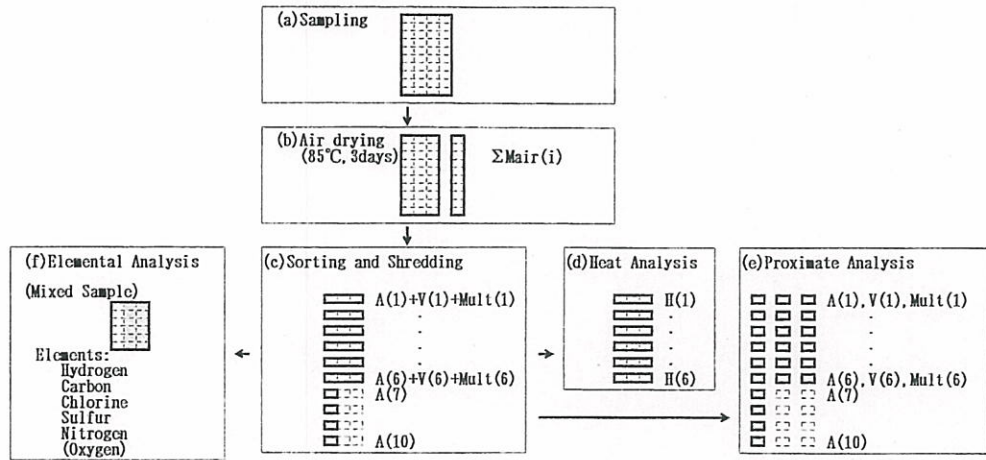


Fig. 3. Analytical protocol.

$$\text{Total Moisture Content} = \sum (Mair(i) + Mult(i)) / W \times 100(\%) \quad (3)$$

where W is weight of raw waste ($W = \sum V(i) + A(i) + (Mair(i) + Mult(i))$).

Heat per unit mass ($H(1)$ – $H(6)$) was measured for all combustible components. Heat from incombustibles was zero ($H(7)$ – $H(10) = 0$). Total heat per unit mass of raw waste was calculated as below:

$$H_{total} = \sum ((A(i) + V(i)) / W \times H(i)) \quad (4)$$

With the combustion process, total heat cannot be available, because a certain amount of heat is consumed to evaporate the water which comes from moisture and hydrogen. Therefore, available heat is less than total heat also known as 'lower heat', 'true heat' or 'net heat'. Available heat per unit mass was calculated as follows:

$$H_{available} = H_{total} - 0.6 \cdot (\sum (Mair(i) + Mult(i)) + 18/2 \cdot (\text{hydrogen})) / W \quad (5)$$

where (hydrogen) is mass of hydrogen. For elemental analysis, it was assumed that all volatile matter consists of hydrogen, carbon, chlorine, sulfur, nitrogen and oxygen.

Fig. 3 describes the analytical protocol. The weight of sample is given by $\sum A(i) + \sum V(i) + \sum Mult(i) + \sum Mair(i)$ (Fig. 3(a)). First total air dryable moisture ($\Sigma Mair(i)$) was obtained (Fig. 3(b)). The sample was then sorted into 10 categories ($A(i) + V(i) + Mult(i)$ ($i = 1-10$)) were determined) and crushed to yield the six combustible components (Fig. 3(c)). Heat analysis was performed on the combustibles (Fig. 3(d)). Proximate analysis for combustibles was carried out ($A(i)$, $V(i)$, and $Mult(i)$ were determined (Fig. 3(e)). Elemental analysis was performed only on the mixture of combustibles. Each unit process is given below.

One tonne of raw waste was picked up with a crane from the pit of a combustion plant. The sample was reduced to ca. 20 kg homogeneously. The weight of the sample ($W = \Sigma A(i) + \Sigma V(i) + \Sigma(\text{Mult}(i) + \text{Mair}(i))$) was then measured.

Samples were air dried for 3 days at 85°C, then cooled at air temperature for 1 day. The difference of the weight gives total air dryable moisture ($\Sigma \text{Mair}(i)$). Air-dried samples were sorted into ten categories and weighed ($A(i) + V(i) + \text{Mult}(i)$, $i = 1-10$). The six combustible components were then crushed to a size small enough to pass through a 1 mm screen. To obtain ultimately dryable moisture ($\text{Mult}(i)$, $i = 1-6$), crushed samples in crucibles were dried at 105°C for more than 16 h and weighed. Ignition at 600°C for 2 h was employed to determine volatile matter ($V(i)$) and ash ($A(i)$). Heat measurement was carried out with an automatic bomb calorimeter. Analytical samples contain ultimately dryable water; therefore, analytical results must be converted into dry base to obtain heat per unit mass.

Elemental analysis was performed only on 'mixtures of combustible components'. This required mixing of the crushed samples as represented by the hatched area in Fig. 2. Hydrogen and carbon were measured using the Liebig method with some modification. Briefly, 1 g of sample mounted on a boat vessel was combusted in oxygen gas in a quartz tube. The combustion gas passed through a calcium dichloride tube (H_2O trapping) and soda talc tube (CO_2 trapping). The weight change of each tube gives the generated H_2O and CO_2 , respectively. To avoid interference from chloride, a silver column at 400°C was placed in front of the calcium dichloride tube. Chlorine and sulfur were analyzed by combustion-gas absorption with 3% hydrogen peroxide-chloride ion/sulfate ion analysis. There are two methods of combustion: gas absorption, or quartz tube combustion and bomb combustion. Data presented in Fig. 2 are based on the quartz tube method. The apparatus used is illustrated in Fig. 4. The method is similar to the 'combustion tube type air method' in Japan Industrial Standard (JIS) K2541 [6].

Samples are combusted in a quartz tube heated with the 'transfer furnace' followed by gas washing. Typical operation conditions are as follows:

Temperature of fixed furnace: 900°C;

Temperature of transfer furnace: 800°C;

Oxidizing gas: 2.5 l/min of moisturized air;

Sample size: 500 mg;

Gas trapping agent: 3% hydrogen peroxide(25 ml + 15 ml).

Bomb combustion is carried out using a bomb for calorimetric analysis. Absorber (25 ml of 3% hydrogen peroxide) is placed in the bomb prior to combustion. Pressurized oxygen gas (30 atm) is introduced and the bomb is electrically ignited and then cooled in water, after which the inner gas is gently drawn. The residue and the inside of the bomb are rinsed with distilled water and combined with absorber.

Chloride and sulfate ion were quantified by ferricyanide colorimetry and barium sulfate precipitation nephelometry, respectively. Nitrogen was analyzed by the Kjeldahl method; 1 g of sample is decomposed by heated sulfuric acid with catalyst (mixture of copper sulfate and potassium sulfate (2:5)). An aliquot of the extract is brought to alkali and ammonia gas is stripped by steam distillation. The ammonia gas is trapped in saturated boric acid and titrated with sulfuric acid. Oxygen is not

directly determined. The difference between total volatile matter ($\Sigma V(i)$) and the sum of other elements is assumed to be oxygen.

4. Results and discussion

Fig. 2 shows the composition of waste in Osaka city over recent years. A summary based on averages is given below.

The major waste component is 'paper' at 262 g-dry/kg-raw waste followed by 'Plastic, rubber and leather' and 'small tips'. In Osaka city, 90 g/kg is incombustible waste, which is rather high compared to other cities in Japan. However, in Osaka city, incombustible waste is collected together with combustible waste.

The range of values of heat per unit mass of each combustible component remained consistent. 'Wood and Leaves' had the smallest range: 4541 ± 298 kcal/kg, while the largest was that of 'small tips': 2930 ± 669 kcal/kg. Variations are attributed to differences in ash content and quality of volatile matter: i.e. if a sample contains sand, the heat per unit mass decreases. Moreover the cellulose-lipid ratio also gives variable heat per unit mass.

One tonne of raw waste consists of 362 kg moisture, 169 kg ash and 469 kg volatile matter. The ash is of two types: ash of combustible components ($\Sigma A(i)$, $i = 1-6$) and ash of incombustible components ($\Sigma A(i)$, $i = 7-10$). Such analysis is useful for ash mass balance estimation in a municipal waste incinerator. It is important to understand how the ash is generated. The mass balance was estimated using ash sampling and flue gas measurement techniques in a Nishiyodo municipal

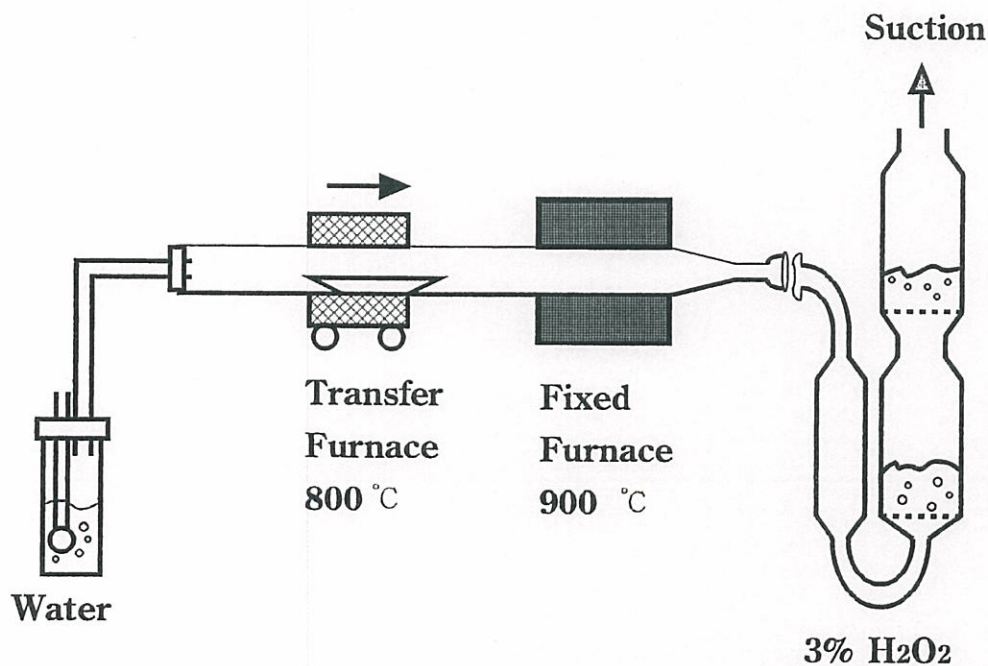


Fig. 4. Quartz tube combustion.

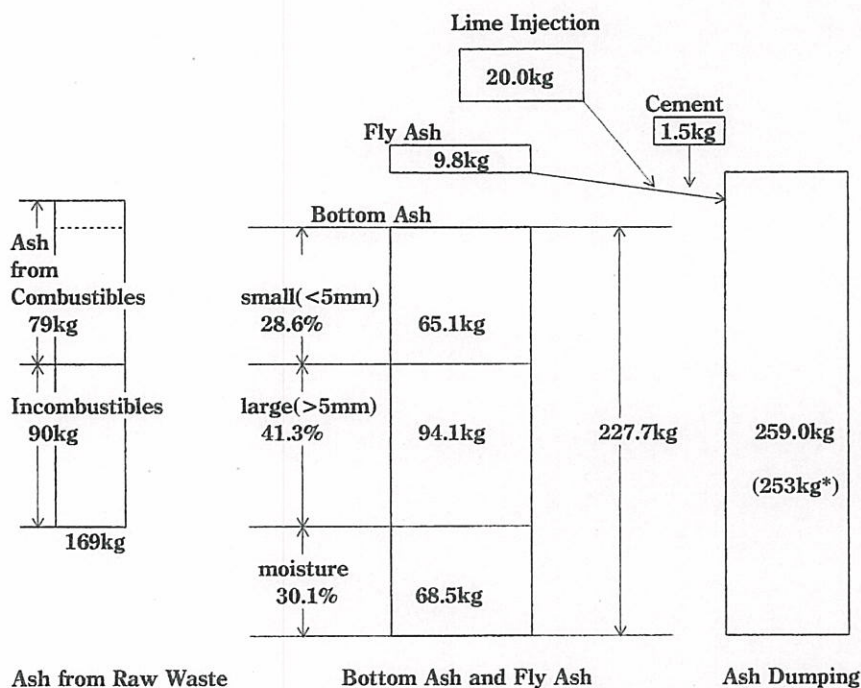


Fig. 5. Comparison of ash mass balance in the Nishiyodo municipal waste incinerator and the origin of ash in raw waste.

waste incinerator in Osaka city (Fig. 5). Bottom ash was sampled from the conveyer between the ash quenching pool and ash pit. Moisture, large particle (> 5 mm), and small particle (< 5 mm screen) content were determined. The result from triplicate sampling was as follows: $30.1 \pm 2.4\%$, $41.3 \pm 3.9\%$ and $28.6 \pm 3.1\%$, respectively. The amount of fly ash was estimated to be 9.8 kg/t raw waste, which is the product of the dust concentration in the flue gas before the bag house precipitator (1.90 g/Nm^3 dry) and flow rate ($5180 \text{ Nm}^3\text{-dry/t raw waste}$). Ash mass balance was estimated as below:

$$(\text{Ash of raw waste}) = (\text{Fly ash}) + (\text{Small particle}) + (\text{Large particle}) \quad (6)$$

$$(\text{Small particle})/(\text{Large particle}) = 28.6/41.3 \quad (7)$$

Thus, small particle and large particle content was 65.1 and 94.1 kg/t raw waste, respectively. While the moisture content of bottom ash was determined to be 66.4 kg/t raw waste.

In the Nishiyodo incinerator, lime at 20 kg/t raw waste was injected into flue gas at the inlet of the bag house precipitator. Ash from the bag house was treated with cement (1.5 kg/t raw waste) to stabilize heavy metal. The total weight of dumped ash was calculated to be 259.0 kg/t raw waste. This is comparable with routine records of ash dumping (253 kg/t raw waste).

The large particles were mainly glass, stone and tin, i.e. incombustible waste components. The large particle content in bottom ash was estimated to be 94.1 kg/t

raw waste, which is in good agreement with the incombustible component in raw waste (90 kg/t raw waste). As discussed above, the amount of ash and the ratio of small and large particle can be predicted by waste analysis.

Proximate analysis of air-dried–crushed samples gave similar results in all analytical runs [5]. Ash, volatile matter and moisture content of air-dried samples are presented in Table 1. It is not clear whether the waste presented as ‘dry base’ is ultimately dried or not. It is possible that some components contain moisture to some extent even though it may be referred to as ‘dried’. Table 1 indicates the possible/maximum moisture content of air-dried sample.

Hydrogen and carbon are quantified by measuring the H₂O and CO₂ generated through combustion. Neither remain in residue. Chlorine and sulfur can be measured by either the quartz tube combustion or bomb combustion method. The difference between the two is best assessed with actual waste samples. A comparison was made using annual representative amount of combustibles. Each sample contained a mixture of all the combustibles collected in the relevant year. All measurements were conducted in duplicate and averaged.

Fig. 6 describes the result of chlorine measurement. Data are expressed as concentration of chlorine in analytical sample (mixed combustible) instead of raw waste. The values for both methods were in good agreement, although those for the bomb combustion method were slightly higher. A larger difference was anticipated, because some alkali elements, such as sodium, bind inorganic chlorine in residue. The result means that even inorganic chlorine was transported to the gas absorber. Thus, the following chemical reactions are possible [7]:

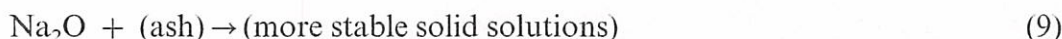


Table 1
Proximate composition of air-dried combustible components

Component	Ash (%)	Volatile matter (%)	Ultimately dryable moisture (%)
	Definition		
	$\frac{A(i)}{A(i) + V(i) + \text{Mult}(i)} \times 100$	$\frac{V(i)}{A(i) + V(i) + \text{Mult}(i)} \times 100$	$\frac{\text{Mult}(i)}{A(i) + V(i) + \text{Mult}(i)} \times 100$
Kitchen garbage	17.17 ± 7.20	74.36 ± 8.92	8.47 ± 4.70
Paper	10.48 ± 2.26	84.63 ± 2.58	4.90 ± 1.46
Textile	6.91 ± 7.34	90.02 ± 7.33	3.07 ± 1.50
Wood and leaves	7.06 ± 6.26	87.26 ± 6.73	5.68 ± 1.70
Plastic, rubber and leather	9.10 ± 4.62	89.53 ± 5.02	1.37 ± 0.86
Small tips	44.63 ± 10.49	51.32 ± 9.91	4.05 ± 1.63

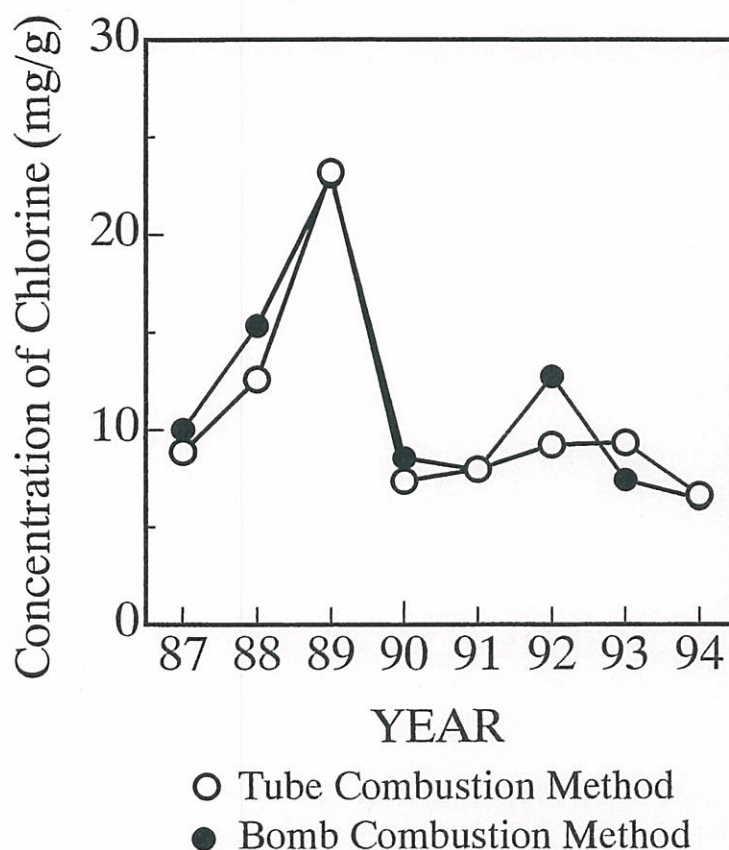


Fig. 6. Comparison of tube combustion and bomb combustion methods in chlorine measurement.

The procedure of this reaction naturally depends on temperature. We carried out an experiment on the efficiency of inorganic chloride transportation versus transfer temperature. Fig. 7 shows the partition of chlorine between residue and absorber versus transfer furnace temperature. Chlorine in residue was determined by water extraction followed by chloride measurement. The higher the temperature of the transfer furnace, the more chlorine was transported to the absorber. This suggests that tube combustion conducted at high temperature gives total chlorine, which can be measured by the bomb combustion method. Moreover, at lower temperatures, significant amounts of chlorine remained in residue.

This means that some chlorine is volatilized and some is not in an actual municipal waste incinerator. The argument so far suggests that tube combustion measurement provides not only total chlorine which can also be measured by the bomb combustion method, but also the lowest hydrogen chloride generation rate in an actual incinerator. The hydrogen chloride release rate from an incinerator can be predicted to be within this range.

The results of sulfur measurement (Fig. 8) obtained by the two methods did not agree; moreover the ratios were not consistent. For example, sodium sulfate will not transport to the gas absorber. No chemical reactions occur to volatilize sulfur. It is

well known that some sulfur remains in ash when coal is combusted. To determine total sulfur with the tube combustion–gas trap method, temperatures as high as 1350°C are required [8]. Such a high temperature is not impossible in an actual waste combustor. Hence, for pollution assessment, the tube combustion method is indispensable.

5. Summary

A method of waste analysis suitable for combustion treatment, which is routinely carried out in Osaka city, was presented. A new versatile format was established by which all components are divided into ash, volatile matter, air dryable moisture and ultimately dryable moisture. Typical waste composition in recent years in Osaka city was also presented.

Ash mass balance estimation around a municipal waste incinerator was compared to the proximate composition of raw waste. It was suggested that the amount of ash and the ratio of small and large particles can be predicted by waste analysis.

Proximate analysis and heat analysis for each combustible component gave similar results even in different samples. Empirical values of these results were presented. The tube combustion and bomb combustion method are compared. Chlorine measurement with tube combustion methods for analyzing chlorine and

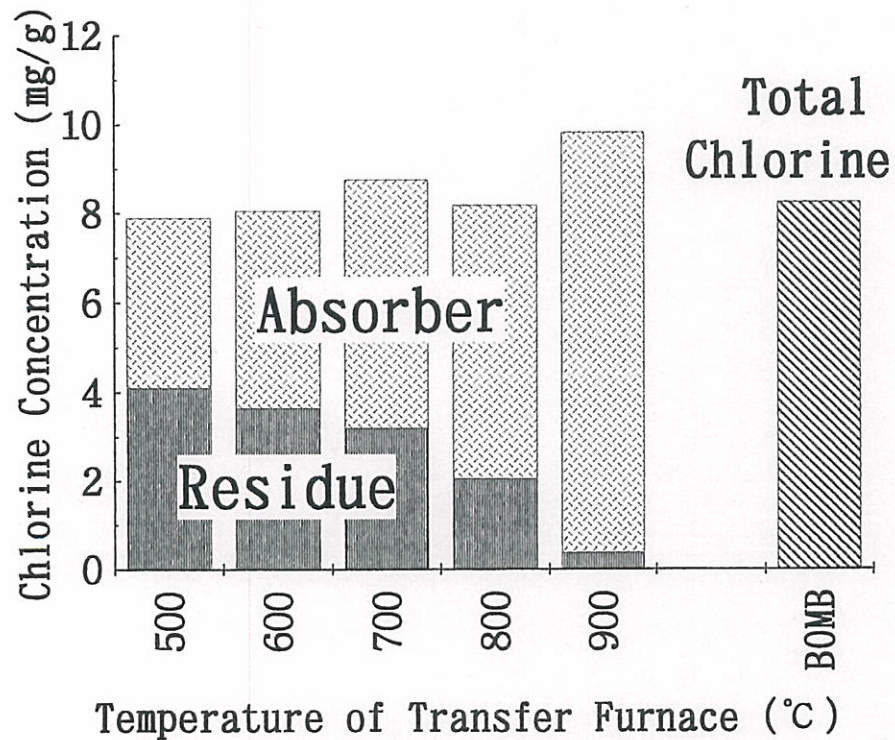


Fig. 7. Chlorine partition between absorber and residue according to transfer furnace temperature.

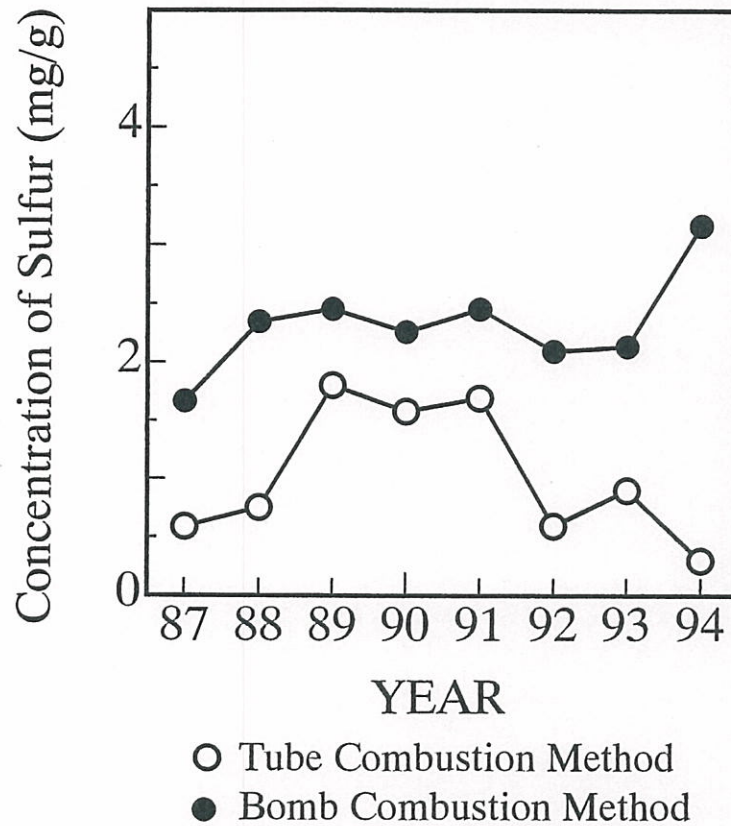


Fig. 8. Comparison of tube combustion and bomb combustion methods in sulfur measurement.

sulfur were compared. Chlorine measurement with the tube combustion was strongly affected by combustion temperature. The tube combustion method gives the lowest hydrogen chloride generation ratio and total chlorine value; the latter can be measured with the bomb combustion method. Sulfur measurement with both methods gave different results. The bomb combustion method gives total sulfur. However, in tube combustion at 800°C, a portion of total sulfur can be released as gas. Thus, the tube combustion method is indispensable for pollution assessment of sulfur oxides.

Acknowledgements

Waste and ash sample, and data on flue gas were provided by the Environmental Management Bureau of Osaka city which controls ten municipal waste incinerators.

References

- [1] Law, S.L and Gordon, G.E., 1979. Source of metals in municipal incinerator emissions. *Environ. Sci. Technol.*, 13: 432–438.
- [2] Domalski, E.S., Churney, K.L., Ledford, A.E., Jr. and Bruce, S.S., 1986. Monitoring the fate of chlorine from MSW sampling through combustion. Part 1: Analysis of the waste stream for chlorine. *Chemosphere*, 15: 1339–1354.
- [3] Japan Ministry of Health and Welfare, 1977. Protocol of waste analysis. In: Notification Kansei 95th (in Japanese).
- [4] Chin, N. and Franconeri, P., 1980. Composition and heating value of municipal solid waste in Spring Creek Area of New York City. In: *Proceedings of National Waste Process Conference*, pp. 239–249.
- [5] Robinson, D.G. and Robinson, W.D., 1986. Raw material quantity and composition: a final check. In: W. Robinson (Editor), *The Solid Waste Handbook*. John Wiley, pp. 507–530.
- [6] Japan Industrial Standards, 1996. K 2541: Crude oil and petroleum products—Determination of sulfur content.
- [7] Kubota, H., Uchida, S., Tsubone, S., Katayama, S., Tsuchiya, K., Suzuki, T., Inukai, S. and Kamo, H., 1982. Volatile chlorine in municipal waste. *J. Solid Liq. Waste*, 12(8): 15–23 (in Japanese).
- [8] Japan Industrial Standards, 1994. M 8813: Coal and coke—Method for ultimate analysis.