Available online at www.sciencedirect.com
ScienceDirect
Waste Management 28 (2008) 2443–2455
waste management
www.elsevier.com/locate/wasman

Change in MSW characteristics under recent management strategies in Taiwan

Yu-Min Chang *, Chien-Chung Liu, Chao-Yang Hung, Allen Hu, Shiao-Shing Chen

Graduate Institute of Environmental Engineering and Management, National Taipei University of Technology, Taiwan, ROC

Accepted 14 October 2007
Available online 31 December 2007

Abstract

Reduction and recycling initiatives such as producer responsibility and pay-as-you-throw are being implemented in Taiwan. This paper presents a study assessing the impact of recently implemented municipal solid waste (MSW) reduction and recycling management strategies on the characteristics of waste feedstock for incineration in Taiwan. Through the periodic sampling of two typical MSW incineration plants, proximate and ultimate analyses were conducted according to standard methods to explore the influence of MSW reduction and recycling management strategies on incineration feed waste characteristics.

It was observed that the annual amount of MSW generated in 2005 decreased by about 10% compared to 2003 and that the characteristics of MSW have changed significantly due to recent management strategies. The heating value of the MSW generated in Taiwan increased yearly by about 5% after program implementation. A comparison of the monthly variations in chemical concentrations indicated that the chlorine content in MSW has changed. This change results from usage reduction of PVC plastic due to the recycling fund management (RFM) program, and the food waste as well as salt content reduction due to the total recycling for kitchen garbage program. This achievement will improve the reduction of dioxin emissions from MSW incineration. In summary, management strategies must be conducted in tandem with the global trend to achieve a zero-waste-discharge country. When implementing these strategies and planning for future MSW management systems, it is important to consider the changes that may occur in the composition and characteristics of MSW over time.

1. Introduction

Taiwan is an island in Asia, 361,000 km^2 in size with a population of 23,600,000. Most of the population is concentrated in the two largest cities: Taipei in Northern Taiwan, and Koushung in Southern Taiwan. Municipal solid waste (MSW) management has become one of the central urban issues confronting Taiwan. In Taiwan, an array of waste management and disposal strategies have emerged, including landfilling, recycling, composting and incineration. Many lawmakers, local city councils and civil groups have proposed ideas to reduce MSW generation, such as restrictions on the use of plastic shopping bags and tableware in Taiwan. Currently, landfilling, recycling, composting and incineration remain critical elements of the MSW management strategy in Taiwan. The availability of substantial, suitable acreages of land is necessary for land disposal systems to be an exclusive, cost-effective waste management strategy. This disposal method proved to be efficient and inexpensive until changes in waste composition and past disposal methods resulted in groundwater contamination and other problems (Kirkeby et al., 2006; Williams, 1998). These problems caused landfill costs to increase over 300% in some Taiwan areas, with predicted costs increasing because of the potential remediation costs and the need to provide long-term monitoring. In view of the ever-soaring costs of disposal, many municipalities are seeking other methods and solutions to manage MSW (Yeomans and Huang, 2003). However, the modern municipal waste incinerator is a sophisticated system designed for the complete, high-temperature destruction

* Corresponding author. Tel.: +886 2 27712171; fax: +886 2 27714237.
E-mail address: ymchang@ntut.edu.tw (Y.-M. Chang).

0956-053X/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.wasman.2007.10.014

of waste. It includes significant post-combustion controls for the removal of undesirable emissions (Holmgren and Henning, 2004).

In Taiwan, each person generates approximately 0.91 kg/day of MSW, of which about 80% is collected by municipalities. As shown in Table 1, approximately 7.51 million tons of MSW were collected in 2005, including roughly 1.75 million tons of recycled material and 0.46 million tons of recovered food waste. The amount of MSW generated is decreasing each year because some programs like pay-as-you-throw (PYT) and total recycling of kitchen garbage (TKG) have been successfully executed. Approximately 60% of the MSW is disposed of by incineration and 30% by landfilling.

Integrated waste management recovers valuable raw materials and energy and reduces the volume of waste sent to landfills (Li and Huang, 2006). Refuse-to-energy (RTE) technology is an important component of integrated waste management systems, and when combined with recycling, composting, and other waste reduction processes, it minimizes the overall disposal costs (Chang and Chen, 1993). In terms of MSW disposal, the Taiwan EPA has adopted a strategy favoring incineration as the primary treatment method with landfills used as a supplement. According to the early "Engineering Project for the Construction of Refuse Incineration Plants", there are 21 large operational RTE facilities in Taiwan. However, a number of technical issues remain for the mass-burn systems, and further research is warranted in Taiwan. One of the issues is dioxin emission control, which seems to be a problem in the early-designed plants. Dioxin emissions continue to be a major issue in obtaining permission applications and in public relations. Despite numerous technological advances in solid waste combustion, increasing resistance among many public officials inhibits the use of incineration as a rational waste management strategy. (Bébar et al., 2002; Consonni et al., 2005; Thipse et al., 2002).

To achieve these objectives and operate in coordination with RTE plants, the Taiwanese government assists local governments in constructing "reusable garbage separation plants". In addition, other treatment methods like "food residue and garbage recycling and reuse" and "jumbo-sized waste recycling and reuse" are utilized to separate and classify MSW and general industrial waste as reusable waste. Through proper sorting, MSW and treated MSW remains are recycled and reused. By doing this, both MSW generation and final disposal will be properly handled (Dioxin and Langer, 2006). Environmental and sanitary conditions will be improved and public health can be well-maintained. Major recycling initiatives implemented in Taiwan include producer responsibility programs and pay-as-you-throw programs. Most people are extremely concerned with the promulgation effectiveness of the recent management programs for MSW reduction. However, information on MSW composition is important in evaluating incineration performance, management programs and plans. Therefore, the major objective of this paper is to study changes in MSW waste characteristics resulting from the recent reduction and recycling management strategies in Taiwan (Koufodimos and Samaras, 2002; Tchobanoglous et al., 1993; Wu et al., 2006).

2. MSW management programs

As listed in Table 2, the management programs for the strategy of MSW reduction and recycling are as described below.

2.1. Pay-as-you-throw (PYT)

Prior to July 2000, waste collection and treatment fees collected by the Taiwanese government were calculated according to the volume of water consumed by a household. Some cities in Taiwan, like Taipei City, collect fees according to the volume of trash discarded. In this regard, Taipei City promulgated a "Municipal Waste Cleaning Fee Collection Ordinance" in August 2000. According to this Ordinance, citizens must pay for and use special trash bags

Table 1
Disposal methods for MSW in Taiwan from 1995 to 2005

Year	Quantity for various disposal methods (ton)											Ratio of recovered food waste (%) (9)	Rate of complete disposal (%) (10)
	Total (1)	Incineration (2)	Sanitary landfill (3)	General landfill (4)	Dumping (5)	Regulated recovery (6)	Others (7)	Recovered food waste (8)	Utilization of food waste				
									Fertilizer	Pig feed	Other utilization		
1995	9,529,687	1,301,036	4,362,789	2,537,556	776,863	45,128	500,033	6282	6282	0	0	0.07	86.60
1996	9,582,643	1,364,639	4,823,997	2,090,514	790,099	56,124	454,750	2520	2520	0	0	0.03	87.01
1997	9,628,644	1,691,626	5,129,676	1,536,415	649,544	98,325	508,885	14,173	14,173	0	0	0.15	87.97
1998	8,992,239	1,741,095	5,597,979	1,088,934	296,545	111,753	155,405	528	528	0	0	0.006	94.97
1999	8,715,575	2,020,634	5,366,936	857,267	245,183	149,876	56,186	19,493	19,242	251	0	0.22	96.54
2000	8,353,368	3,229,750	3,822,124	697,050	119,116	477,856	4690	2782	2659	123	0	0.033	98.52
2001	7,839,175	3,736,891	2,996,805	433,330	73,040	584,333	14,560	216	216	0	0	0.003	98.88
2002	7,601,960	4,316,049	2,116,375	224,477	55,076	878,319	7958	3706	3506	150	50	0.05	99.17
2003	7,555,372	4,304,574	1,900,438	113,115	20,190	1,048,981	734	167,304	22,290	139,614	5400	2.21	99.72
2004	7,522,263	4,305,822	1,458,234	59,792	15,004	1,387,371	1201	294,799	64,950	221,559	8290	3.92	99.78
2005	7,505,419	4,153,760	1,105,224	36,332	2585	1,749,952	104	460,137	95,820	357,473	6844	6.13	99.96

Remark: (1) = (2) + (3) + (4) + (5) + (6) + (7) + (8) (9) = (8)/(1) (10) = [(2) + (3) + (4) + (6) + (8)]/(1).

Table 2
A summary of recent management programs for MSW reduction and recycling

Program name	Abstract
Pay-as-you-throw (PYT)	The program asks citizens to pay waste collection and treatment fees through the purchase of special trash bags approved by the Government. Based on trash volume, the price rate of the special trash bags includes trash collection and treatment fees. Recyclables separated by citizens are collected free-of-charge by the local cities
Total recycling for kitchen garbage (TKG)	The program is based on some physical pretreatment processes. MSW classifications and recycling prior to incineration through bulky waste recycling (e.g., waste furniture or waste electronics), and proper garbage sorting done by the separation plant, several waste categories after sorting are: recyclable and reusable, repairable and reusable, combustible and non-combustible. As a consequence, kitchen garbage is asked to be separated from MSW by hand. Local governments enforce administrative propaganda and education to improve the collection efficiency of kitchen garbage, as possible
Restricted use on plastic shopping bags and plastic tableware (RUP)	To advocate simple life and gradually improve plastic material use, enforcement of the program includes restricted targets that are not allowed to offer plastic bags containing PE, PP, PS, and PVC processed through blow molding, rolling, extruding and other methods, with the thickness of plastic shopping bags under 0.06 mm. The program asks that the cost of the plastic bags not be included in the price of merchandise paid by consumers
Producer responsibility program (PRP)	The program asks that the producers/manufacturers of regulated goods take responsibility for recovering spent goods discarded by users at a regulated recovery rate every year. The regulated goods items have increased gradually in recent years. Targeting a 10% reduction rate for MSW in 2006 and increasing to 15% in 2008, the Taiwanese EPA expands the scope of the producer responsibility program by developing new recycling techniques and strengthening the municipalities' recyclable collection programs
Recycling fund management (RFM)	Recycling fees paid by manufacturers/importers are distributed to the recycling management fund (RMF), which comprises a segment of EPA's budget and is administered by the Recycling Fund Management Committee. The RMF, established under the Waste Disposal Act and administered by the Taiwanese EPA, asks the manufacturers or importers of listed items to pay recycling fees to the RFM. The EPA then uses the recycling funds to subsidize collection and recycling

for trash to be collected by Taipei City. The price for the special trash bags includes trash collection and treatment fees, whereby citizens pay waste collection and treatment fees through the purchase of special trash bags approved by the Government. The current fee rate is NT$0.45 (approximately US$0.013) per liter of trash. Sorting mandated by the program has resulted in a significant reduction in MSW. As listed in Table 1, the quantity of MSW generated in Taiwan has dropped from 8.35 million tons in 2000 to 7.51 million tons in 2005. In the other areas of Taiwan, the pay-as-you-throw program is also being utilized. Recyclables that are separated by citizens are collected free-of-charge by local cities. Individuals caught counterfeiting the special trash bags will be fined between NT$30,000 and NT$100,000 and may be subject to criminal penalties (Hallas-Burt and Halstead, 2004).

2.2. Total recycling for kitchen garbage (TKG)

The TKG program involves certain physical waste pretreatments before disposal. It focuses on waste from residential areas, restaurants and hotels. MSW classifications and recycling are usually done prior to incineration through recycling of bulky waste, like furniture or electronic waste, and proper garbage sorting. Residential waste is collected after sorting into four kinds: recyclable/reusable, kitchen garbage, incinerable and non-incinerable. The program encourages housekeepers to separate food waste from the kitchen garbage before discharge. Combustible waste is sent to incinerator plants while recyclable wastes like paper, metal and plastics are sent to resource recycling plants. Non-combustible materials are sent for forest planting or forest ground filling.

Kitchen garbage is generally composed of food waste. Most food waste can be separated, with some used as pig food and the rest turned into fertilizer by composting. The enhancement of soil organics is comprised of soil acidification. Taiwan aims to reuse all food waste, either as a pig food or fertilizer by composting, thus reducing the need for landfills. It is also worth noting that, at the local government level, food wastes have been the focus of recycling programs in recent years. For instance, Taipei city began collecting household food wastes in April 2002.

2.3. Restricted use on plastic shopping bags and plastic tableware (RUP)

The RUP program aims to restrict the use of plastic materials. This is difficult to achieve because habits cannot be changed overnight, due to concerns about food and beverage hygiene. At the current stage, the program restricts the use of those plastic materials that may result in serious environmental pollution. The ultimate goal of this program is waste source elimination. The Taiwan EPA found the best way to restrict the use of plastic bags and plastic tableware was by dividing the program into stages and determining restricted use targets to gradually enforce the policy.

With gradual enforcement methods that stipulate scheduled stages aimed at restricting use and disposal of plastic shopping bags and plastic tableware (including styrofoam), the program adopts incentives and funding to encourage voluntary vendor observation of the restricted use of plastics. The targets in the first stage of restricted use are government agencies on all levels, government-run enterprises, military units, national military general stores, public and private schools, and public hospitals. The first stage was scheduled to commence in July 2002. However, because of a prolonged drought and water rationing in some areas, the restricted use of plastic tableware was extended to January 2003. The targets in the second stage of restricted use are the department stores, large-scale markets, supermarkets, chain stores, and fast food chain stores plus the food and beverage stores with a shop front. The second stage commenced in January 2004.

The main enforcement method is that restricted targets are not allowed to offer plastic bags containing PE, PP, PS, and PVC processed through blow molding, rolling, and extruding; the thickness of the plastic shopping bags is restricted to less than 0.06 mm. The program demands that the cost of the plastic bags not be included in the price of the merchandise and that consumers must pay for the plastic bags. However, the program does not include plastic bags in the form of merchandise packaging and on-shelf sale exhibits, such as those used for packing fish, meats, vegetables, fruits and other raw merchandise or foods. Other items, such as packaging materials adopted in factories and packaging materials that contain medicine for use in hospitals, have also been excluded.

2.4. Producer responsibility program (PRP)

This program was announced in 1998 and commenced in July 2000 under the Waste Disposal Act (promulgated in 1974). It demands that the producers/manufacturers of regulated goods take responsibility for recovering the goods that users discard at a regulated recovery rate annually. The number of regulated goods has increased in recent years. Past research and development projects have focused on fluorescent lamps, foam plastics, dry batteries, aseptic containers for agricultural chemicals, liquid crystal displays (LCD), cathode ray tubes (CRT), and printed circuit boards. To expand the scope of producer responsibility, the Taiwanese EPA proposes to subject microwave ovens, electromagnetic ovens and electric clothes dryers to the recycling requirements under the Waste Disposal Act beginning in September 2002. Moreover, the EPA is studying whether subjecting compact disks (CDs) to these requirements is feasible. With respect to strengthening municipality collection systems, the EPA will continue to provide local governments with grants to establish collection and sorting facilities, and offer training courses for employees engaged in waste collection. Furthermore, the EPA evaluates the performance of municipalities in the area of waste minimization and rewards municipalities for outstanding efforts in this regard each year.

Most industries have their origins in recycling, like pulp, paper and electricity industries. Recycling industries have achieved significant technological breakthroughs in the past 20 years, such as the development of the automobile shredder and the recycling of lead batteries (Mrayyan and Hamdi, 2006). To promote recycling, the Taiwanese EPA has actively regulated and administered the program, while local governments have implemented pay-as-you-throw and mandatory sorting programs. At the national level, the Taiwanese government plans to expand the scope of producer responsibility to cover the entire product life cycle using the Resource Recycling and Reuse Act law (RRRA, promulgated in July 2005). The program has promoted the recovery and reuse rate for many goods, and thus reduced refuse, which is estimated roughly at 2–5% of the MSW reduction rate every year due to the PRP program implementation, and targets a 10% reduction rate for municipal wastes in 2008. The Taiwan EPA expands the scope of the producer responsibility program by developing new recycling techniques and strengthening the recyclable collection systems of municipalities.

2.5. Recycling fund management (RFM)

The scope of the program is that recycling fees paid by manufacturers/importers are distributed to the recycling management fund (RMF), which comprises a segment of EPA's budget and is administered by the Recycling Fund Management Committee. Currently, the RMF, established under the Waste Disposal Act and administered by the Taiwan EPA, asks the manufacturers or importers of listed items (including containers, batteries, cars, motorcycles (scooter), tires, oil, televisions, refrigerators, air conditioners, washing machines, computers, and printers) to pay recycling fees to government recycling funds. The EPA then uses the recycling funds to subsidize collection and recycling.

The total budget in 2005 for the RMF is roughly US$200 million; 70% of the funds is distributed to trust funds, which are used to subsidize the collection or treatment for regulated items based on certified collected or treated volumes. The remaining 30% is distributed to non-enterprise revolving funds, which are dedicated to education, research and development, audit and certification, grants for municipalities and citizen groups, and administration.

3. Sampling and analysis methods

Two typical plants, denoted as A and B and chosen from 21 RTE plants, were used as sampling objectives in this study. These plants are located in the typical urban cities, where populations are the top two in Taiwan. The programs described above have been performed more completely in the cities where plants A and B are located relative to other cities. The design capacities for incineration are 900 and 1350 tons of MSW per day for plants A and B, respectively. To obtain representative data, sampling studies of these two plants were conducted monthly in 2003 and 2005, respectively. Due to refuse sources characterized by distinct layers or stratification, probability sampling was designed so that samples, which had an equal chance of being chosen, were collected randomly to provide maximum accuracy. The sampling method provides a statistically valid means of determining the dimensions of sampling units and the number of samples collected for three-dimensional waste in a refuse bunker with necessary stratified random sampling. A specified error of 5% corresponding to a 95% confidence level was applied, and thus the sample values were an accurate estimate of the true values. A precision level of 10% was required for all measurements in this work.The sampling method procedures for measuring the physical composition of unprocessed MSW followed the NIEA (National Institute of Environmental Analysis, Taiwan) test method R124.00C (referred to ASTM D5231-92). This test method determines of the mean composition of MSW based on the collection and manual sorting of a number of waste samples (Petersen et al., 2005).

In general, waste was collected at a weight of 1200 kg from a refuse bunker using a crane. This waste was then reduced to about 50 kg by cross-mixing. The 50 kg sample was separated into different physical categories. Each physical category was classified into a few sub-categories based on rough chemical composition differences. For example, paper was classified into eight sub-categories as shown in Table 3. Each sub-category was weighed on site and taken to a laboratory for proximate and ultimate analyses.

Table 4
Sampling and analysis methods for the MSW generated in Taiwan in this study

Items		NIEA code (Taiwan)	ASTM code (reference)
Sampling		R124.00C	D5231-92
Physical composition		R125.01C	D2795, D3682
Proximate	Moisture	R213.20C	D3172
	Combustible	R205.01C	
	Ash		
Ultimate (element): C,H,N,S,Cl		R404.21C	D3176
Heating value		R214.01C	D3286-96

The proximate and ultimate analyses were conducted for each sub-category sample following the standard methods listed in Table 4. The sub-category data for the proximate or ultimate analysis was averaged to a mean value for each physical component by weighting the data of its sub-categories. For example, while analyzing chlorine in paper waste by NIEA R404.21C, the sub-category samples were oxidized by combustion in a bomb containing oxygen under pressure. Thus, the chloride compounds were liberated and absorbed in a sodium carbonate solution and the amount of chlorine was determined gravimetrically by precipitation as silver chloride. With weighting factors, all chlorine data of sub-category papers were averaged to a mean value for paper waste.

4. Characteristics of MSW waste

As listed in Table 5, a series of analyses for MSW properties were conducted in this study, including analysis of

Table 3
Category of physical composition for the combustible MSW generated in Taiwan

Category	Sub-category			
1. Paper	1.1 Copy paper	1.2 Newspaper	1.3 Tissue/towel paper	1.4 Corrugated paper
	1.5 Cardboard/pasteboard paper	1.6 Kraft paper	1.7 Advertising paper	1.8 Biscuit-packed paper
2. Cloth/textiles	2.1 Cotton	2.2 Wool	2.3 Polyester/nylon	2.4 Mixed spin
3. Wood/garden trimmings	3.1 General wood	3.2 Plywood	3.3 Leaves/flowers	3.4 Ricehulls
	3.5 Bamboo (incl.Bamboo chopsticks)	3.6 Bark/cortex		
4. Food waste	4.1 Rice	4.2 Noodle/bread	4.3 Animal bone	4.4 Vegetables
	4.5 Grease/fat/oil	4.6 Eggshell	4.7 Crab	4.8 Peelings
	4.9 Plant seeds	4.10 Tea leaves	4.11 Others	
5. Plastics[a]	5.1 PS (foamed, Styrofoam)	5.2 PS	5.3 PE	5.4 PET
	5.5 PVC	5.6 PP	5.7 Others	
6. Leather/rubber	6.1 Bicycle inner tube	6.2 Bicycle outer tire	6.3 Motorcycle/automobile tire	6.4 Boot
	6.5 Shoe	6.6 Leather bag/belt	6.7 Water hose (rubber)	6.8 Others
7. Other organics	–			

[a] *Remark*: classified by chemical composition.

Table 5
Typical data of characteristics for the MSW generated in Taiwan

Date: 2005.12.20		Sampling site: plant A										Bulk Density: 217 kg/m^3						
Items		Physical composition (weight basis)		Moisture (%)	Ash		Combustible (wet basis) (%)	High heating value (HHV)		Low heating value (LHV)		Chemical element (wet basis)						
Composition		Dry basis (%)	Wet basis (%)		Dry basis (%)	Wet basis (%)		Dry basis (kcal/kg)	Wet basis (kcal/kg)	Dry basis (kcal/kg)	Wet basis (kcal/kg)	C (%)	H (%)	N (%)	O (%)	S (%)	Org.Cl (%)	(C/N)
Combustibles	1. Paper	13.57	13.38	38.84	12.69	7.76	53.40	4235	2590	3561	2178	27.59	3.32	0.74	20.05	1.47	0.22	37.28
	2. Cloth/ textiles	13.67	14.76	44.13	3.92	2.19	53.68	5193	2901	4359	2435	29.17	3.73	2.78	17.97	0.00	0.03	10.49
	3. Wood/ garden trimmings	7.88	7.15	33.57	12.68	8.42	58.01	3943	2619	3370	2239	30.22	3.32	1.06	23.30	0.08	0.04	28.51
	4. Food waste	19.78	30.54	60.93	3.01	1.18	37.90	1879	734	729	285	15.21	1.55	1.01	20.05	0.05	0.02	15.06
	5. Plastics	21.28	17.90	28.29	11.22	8.04	63.67	8012	5746	7251	5200	45.72	6.97	0.19	9.14	0.37	1.28	240.63
	6. Leather/ rubber	4.99	3.69	18.45	6.00	4.89	76.66	4568	3725	4098	3342	37.34	5.04	7.35	25.62	1.24	0.07	5.08
	7. Other organics	7.10	5.34	20.02	6.86	5.49	74.49	3125	2499	2635	2108	39.58	5.03	2.60	26.16	0.65	0.48	15.22
Non-combustible	8. Metals	3.51	2.17	2.33	100	97.67	0	0	0	0	0	–	–	–	–	–	–	–
	9. Glass	2.16	1.34	2.77	100	97.23	0	0	0	0	0	–	–	–	–	–	–	–
	10. Ceramic	1.96	1.20	1.63	100	98.37	0	0	0	0	0	–	–	–	–	–	–	–
	11. Sand/stone and inert	4.10	2.53	2.33	100	97.67	0	0	0	0	0	–	–	–	–	–	–	–
Overall		100.00	100.00	39.69	18.76	11.32	48.99	4122	2486	3423	2065	26.48	3.41	1.34	17.10	0.37	0.29	19.76

physical composition, proximate analysis (moisture, combustible matter and ash), and ultimate analysis and heating value. The results of these individual analyses with discussion are provided below.

4.1. Physical composition

The moisture content in waste components typically shows seasonal variations and the physical composition of waste typically varies based on management practices. Through the field investigation with periodic sampling, the study found that much of the MSW generated in Taiwan is simply trash (including rubbish or garbage). This includes paper and plastics, wood, rubber and leather, old clothing, and a host of other products. Occasionally, however, a few of these wastes are hazardous. By comparing the data obtained in 2003 and 2005, as shown in Fig. 1, the physical components of MSW in plants A and B changed, obviously due to the changes in programs described above.

In 2003, paper or wood waste was usually the largest portion in MSW, but after the previously mentioned programs were initiated, plastic waste became the largest portion of the MSW stream and is predicted to continue growing. During the program, it was found that food waste was the component with the maximum variation among all physical components. This is attributed to the well-applied RKG program in Taiwan. For plant A, the percentage of food waste (dry wt. basis) decreased from 20.5% in 2003 to 15.8% in 2005. The weighted portions of most incombustible components decreased after implementation of these programs. However, plastic waste increased from 16.0% in 2003 to 24.5% in 2005, and textiles increased during the same period from 8.8% to 12.2%.

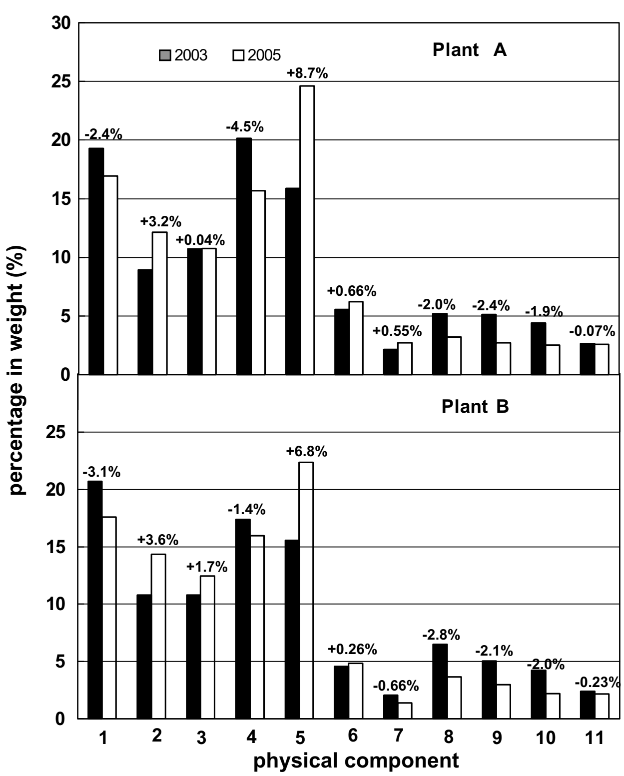

Fig. 1. Comparison of physical components between 2003 and 2005. 1. Paper, 2. cloth/textiles, 3. wood/garden trimmings, 4. food, 5. plastics, 6. leather/rubber, 7. other organics, 8. metals, 9. glass, 10. ceramic, 11. sand/stone.

It is notable that the total amount of plastic waste decreased significantly during the past few years, mainly due to the RUP and PRP programs in Taiwan. It was estimated that the total amount of plastic waste in MSW decreased from about 150 tons/yr in 2003 to 120 tons/yr in 2005. However, the weight percentage of plastic waste in MSW feed to incineration increased even with the usage-limitation policy. This result is attributed to two issues. First, food eaten-out is usually taken out with plastic bags. This causes the bags to become dirty and discarded by the user. Second, plastic usage is the custom in Taiwanese society and will not be easily changed. Merchandise plastic packaging is the norm due to the great amount of rain in Taiwan. By weight, plastic waste currently accounts for about 22–25% of the waste stream. Environmental conditions such as the rainy season also affect the quantity of plastic waste collected in Taiwan. In summary, the programs that meet the recent management strategy for MSW reduction and recycling significantly influence the physical composition of incineration feedstock, especially as related to food waste, paper, and plastics.

4.2. Chemical properties

4.2.1. Proximate analysis

In general, about five-sixths of the MSW (on a weight basis) is comprised of organic or combustible materials. The remaining one-sixth is primarily metals, glass, and dirt. In other words, the combustible components comprise 83–86% (dry wt. basis) (paper, wood/garden trimmings, cloth, plastics, food waste, rubber/leather, and others) of MSW. The concentration of the incombustible components is 14–17 (dry wt. basis) (metal, glass, ceramic and other inert materials) for the MSW generated in Taiwan. As shown in Fig. 2, the average monthly variation in moisture content decreased from 39.9% in 2003 to 37.5% in 2005 for plant A, and from 40.0% in 2003 to 37.0% in 2005 for plant B. The ash content decreased from 15.6% in 2003 to 11.2% in 2005 for plant A, and from 16.0% in 2003 to 11.2% in 2005 for plant B. However, the combustible matter increased from 44.4% in 2003 to 51.3% in 2005 for plant A, and from 44.0% in 2003 to 51.8% in 2005 for plant B, because of decrease in both moisture and ash.

From the periodic data obtained as shown in Fig. 3, it was found that the ash content decreased for both plants A and B from 2003 to 2005. This implies that the MSW recycling management strategy was implemented successfully in Taiwan and, therefore, that most recoverable mate-

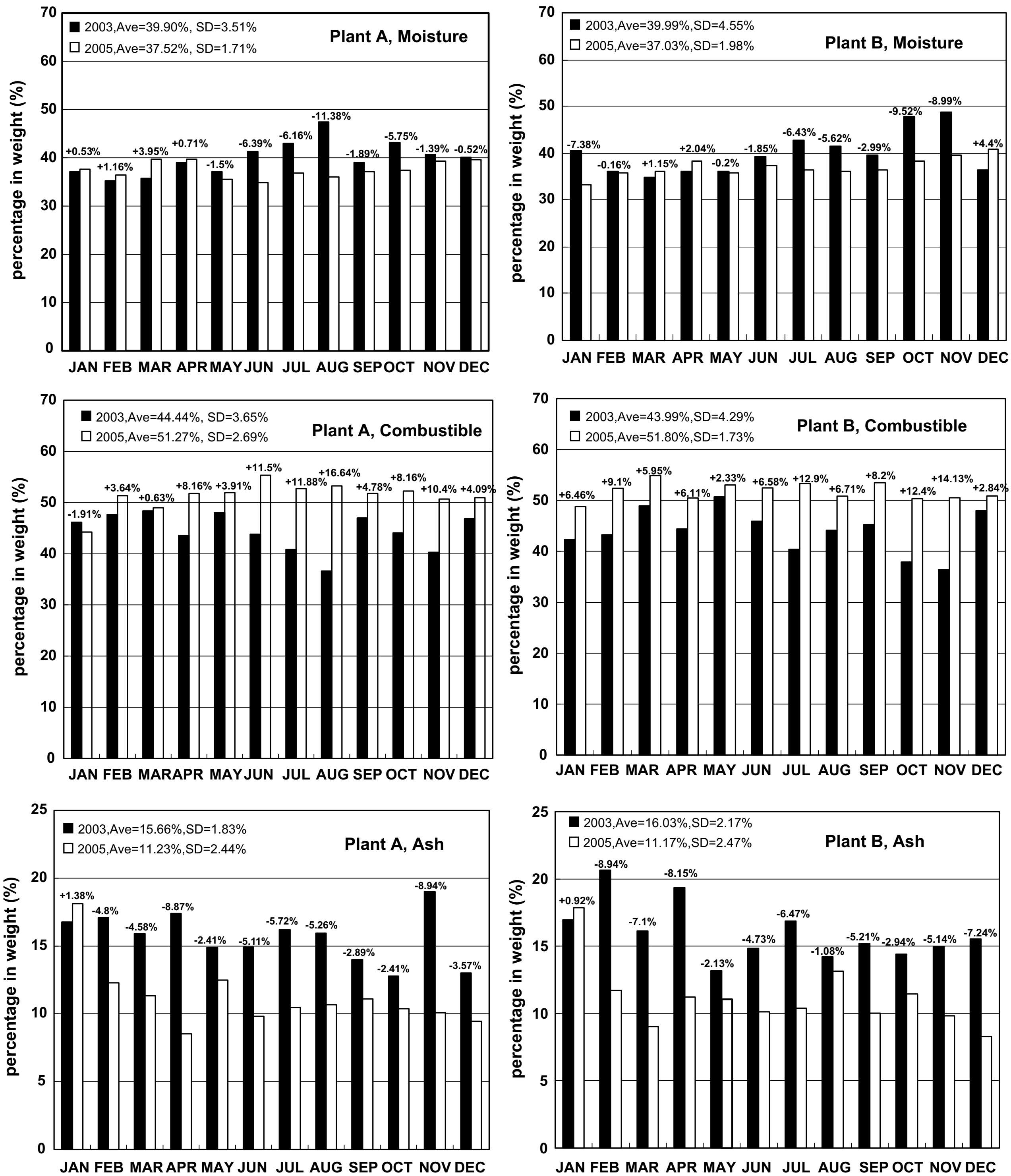

Fig. 2. Monthly variation of moisture, combustible matter and ash for plants A and B.

rial can be recycled through collection systems in communities. The recoverable material usually contains a high ash content; so programs, such as PUP and FRM, would promote decreases in ash content. This achievement would give an incentive for decreasing the bottom and fly ash disposal costs for annual incineration operation and maintenance. In addition, the results also show that TKG programs can reduce the percentage of high-moisture food waste in refuse. This has led to a decrease in moisture content for both plants A and B. This program encourages restaurants to make a greater effort in food waste reduction and encourages local governments to actively strive to establish more collection and recovery programs for food waste in Taiwan. Because of the reduced moisture matter

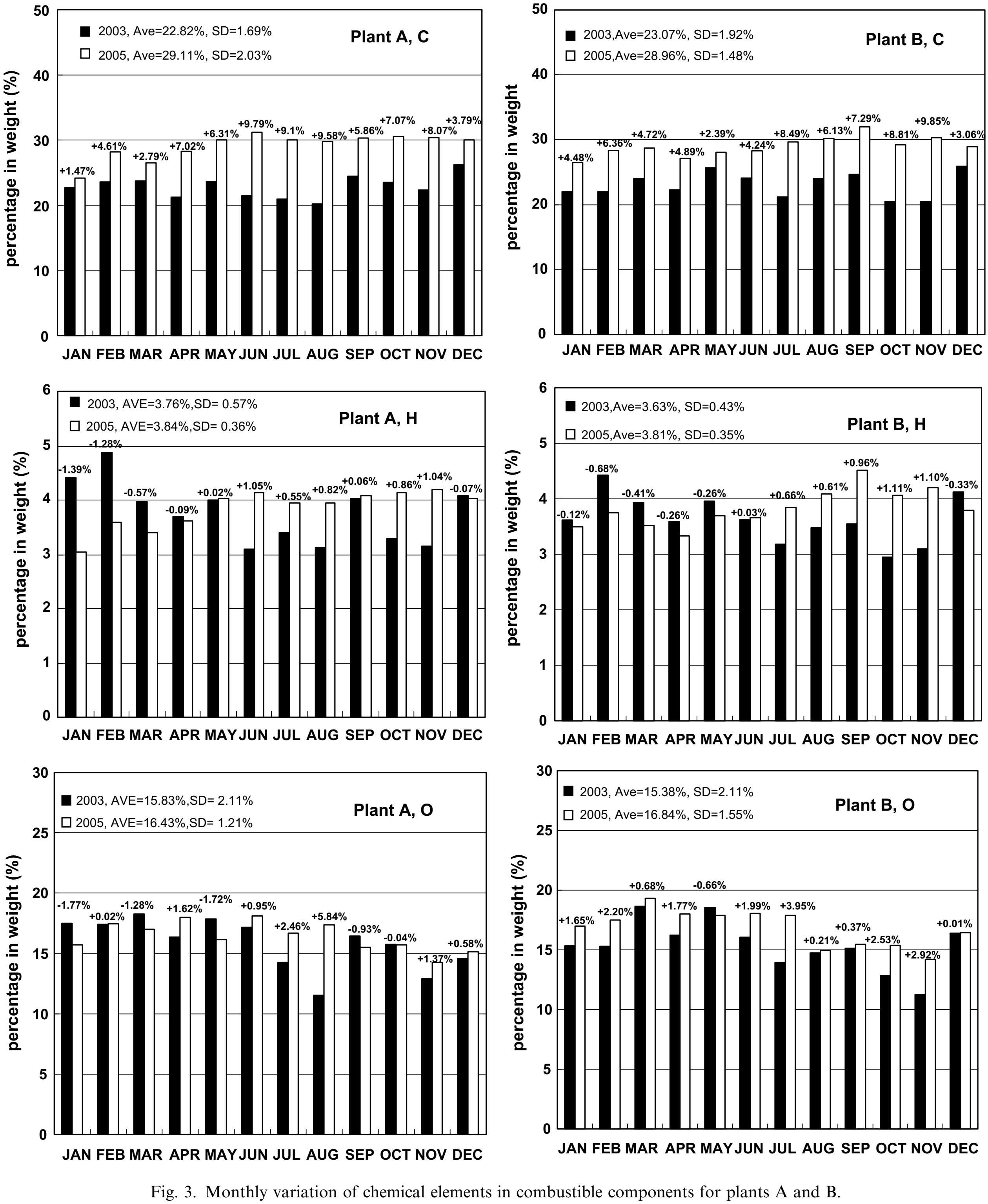

Fig. 3. Monthly variation of chemical elements in combustible components for plants A and B.

and ash due to program implementation, the combustible matter in MSW increased.

4.2.2. Ultimate analysis

The complex waste diversion sources resulting from the recent MSW reduction management strategy are difficult to explore. A comparison of the monthly variation in chemical elements, resulting from the ultimate analyses for organic compounds is shown in Fig. 3. This indicates that carbon is the element with the maximum variation among all elements in the organic compounds. As discussed in the above section, the TKG program affects the percentage of food waste, and the RFM program decreases the non-combustible material in refuse. It was found that the concentra-

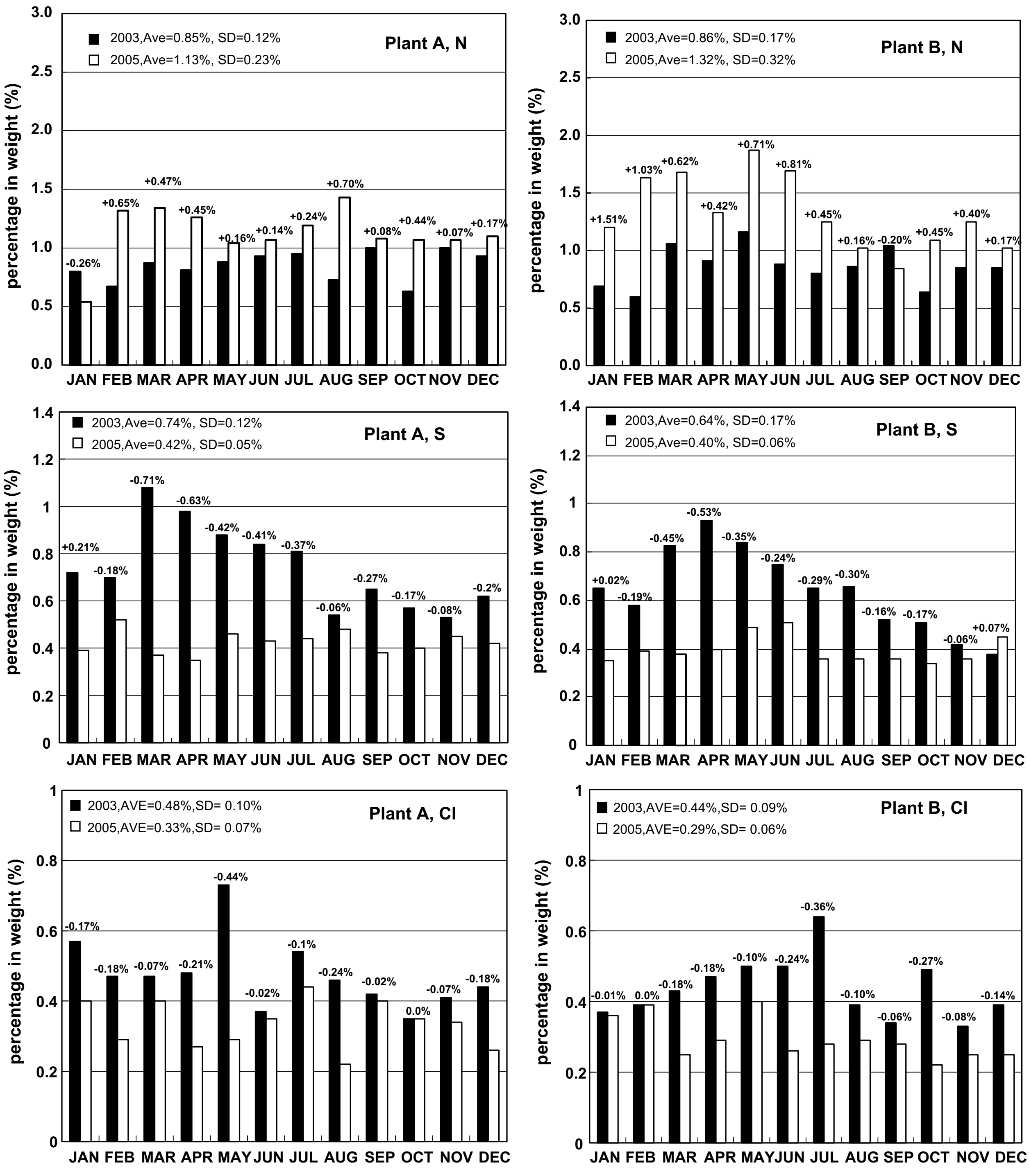

Fig. 3 (*continued*)

tion (by wt.) of carbon increased from 22.8% in 2003 to 29.1% in 2005 for plant A, and from 23.1% in 2003 to 28.9% in 2005 for plant B. This is consistent with the increase in combustible content found by the proximate analysis. It was also found that the concentration (by wt.) of nitrogen increased from 0.85% in 2003 to 1.13% in 2005 for plant A, and from 0.86% in 2003 to 1.32% in 2005 for plant B. However, NO_x emissions were enhanced in the flue gas from the MSW incinerator, thus increasing the De-NO_x cost. This is an resulting problem that will require more attention during program execution.

However, concentration (by wt.) of sulfur decreased from 0.74% in 2003 to 0.45% in 2005 for plant A, and from 0.64% in 2003 to 0.40% in 2005 for plant B. This will be helpful to control the acid flue gas emitted from the MSW incinerator. In other words, the waste diversion resulting from recent management strategies does not lead to an extra treatment load for controlling acid flue gas because of the off-set effect from increasing the nitrogen content and decreasing the sulfur content in the incineration feedstock. In addition, the chlorine content in the waste changed. For plant A, chlorine decreased from 0.48% in 2003 to 0.33% in 2005, and from 0.44% in 2003 to 0.29% in 2005 for plant B. This results from a reduction in PVC plastic due to RFM, as well as the food waste and salt content reduction due to TKG. This achievement would give a benefit to reduce the dioxins emission from MSW incineration. For example, the annual-average dioxins/furans emission decreased from 0.23 in 2003 to 0.07 ng-TEQ/N m^3 in 2005 for plant A, and decreased from 0.15 in 2003 to 0.04 ng-TEQ/N m^3 in 2005 for plant B. This is not completely attributed to those programs, but the strategy to eliminate chloride in MSW is actually a good measure for reducing dioxin/furan emissions from MSW incineration.

In addition, there are low C/N ratios in cloth/textiles, food waste and rubber waste in most cases in Taiwan. If concentrations of these wastes are a little high, the result would be low C/N ratios in MSW. For other elements such as oxygen and hydrogen, the impact of waste diversion resulting from recent management strategies on these elements seems insignificant.

4.3. Heating value

The variation in management programs affects the physical composition of waste feedstock to incineration, and thus changes the heating value. As shown in Fig. 4, the mean lower heating values (LHV) for MSW generated in 2005 were 2009 ± 99 and 1924 ± 160 kcal/kg on a wet basis, and the mean higher heating values (HHV) obtained were 3825 ± 282 and 3729 ± 273 kcal/kg on a dry basis for plant A and plant B, respectively. The heating values in 2005 were minimally higher than those in 2003 for both plants A and B. They increased gradually (about 5% annually) after the programs were implemented, because the reutilization strategy for food waste in kitchen garbage has been popularized recently in Taiwan. The reduction

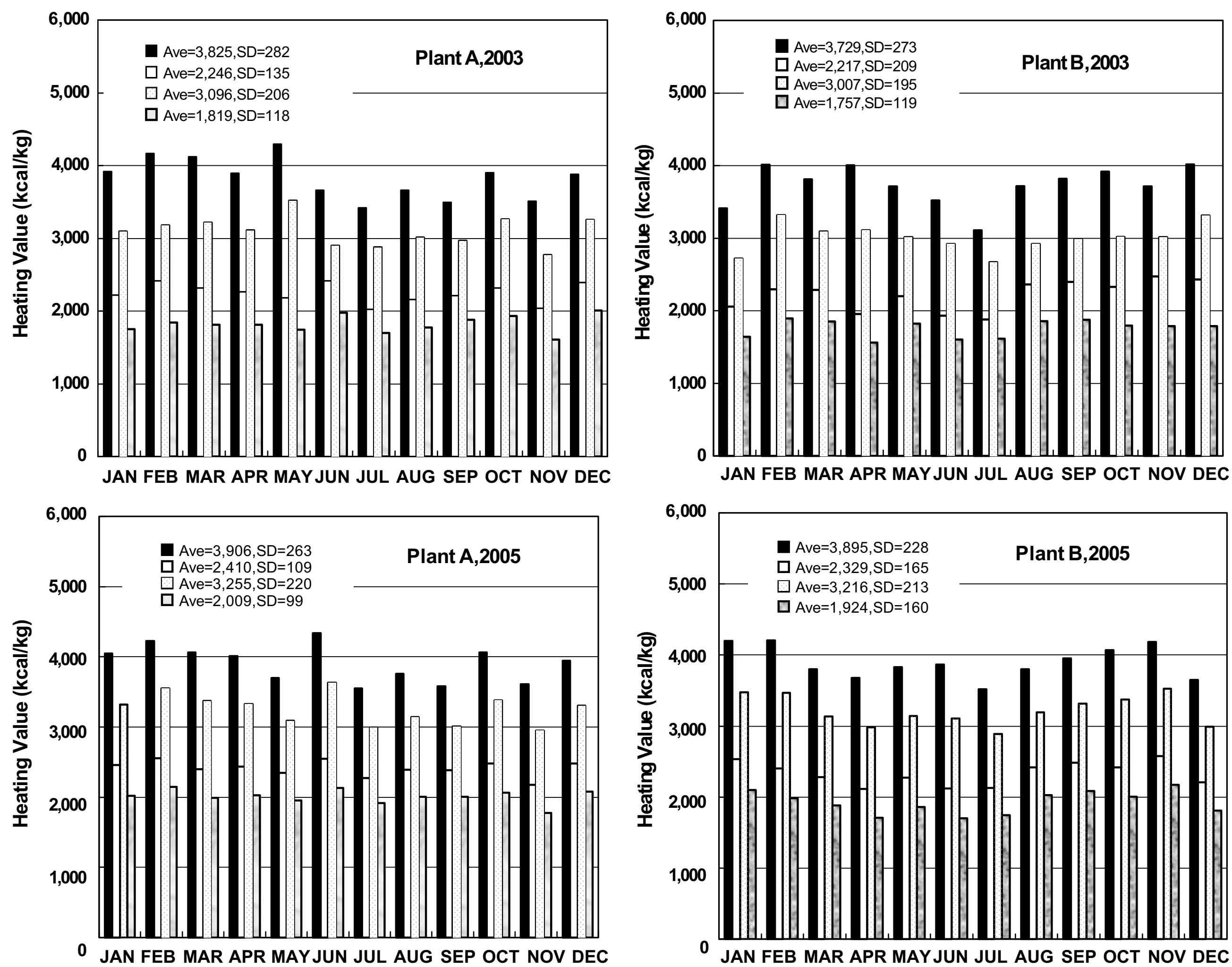

Fig. 4. Monthly variation of heating values for plants A and B (■ HHV, dry basis; □ HHV, wet basis; □ LHV, dry basis; □ LHV, wet basis).

in food waste in MSW decreased the moisture content, and thus increased the heating value. Another reason is the increased percentage of plastic waste in the MSW, as discussed above.

Note that the variation in heating value is remarkable in Taiwan, possibly due to weather variability. Taiwan has many rainy days in the spring and summer. The average annual rainfall is 2800 mm, but there are very heavy rains, about 30% and 45%, in the spring and summer, respectively. In general, the moisture content and plastic component are the key factors that affect the heating value of MSW for most areas in Taiwan. The fluctuation in heating value will affect the stability of generated electricity. In Taiwan, the heat recovery from incinerated refuse is estimated to be in the range of 1.4–2.3 million kcal/ton (mean 2.02 million kcal/ton), if based on the latent steam heat (generally about 400 °C @ 38.5 psig). Therefore, the operating conditions in RTE facilities are adjusted to avoid damage to the heat recovery systems, designed originally in existing RTE facilities (Ettouney et al., 2005).

As more cities adopt legislation mandating the development of source reduction and recycling programs, the composition of the MSW collected will change. The impact of waste diversion on waste composition will vary depending on waste management programs that have been implemented. Therefore, a RTE facility, developed to serve a commercial area, was planned and designed on the basis that the energy content of the waste would be, for example, about 1700 kcal/kg (LHV, wet basis) for both plants A and B. A number of years later when the facility went on line, the actual energy content of the MSW increased to about 2100 kcal/kg, as a result of the previously mentioned programs that had been developed in the intervening years. To meet the contractual requirement to generate a stable amount of power, the number of waste truckloads would be reduced with necessary change in the facility permit.

4.4. Discussion

From the results described above, it was essentially found that the recent MSW management strategy provides some benefits, such as profit from recycling material and lowered O&M cost in final disposal. Most notably, the MSW quantity decreased annually, as shown in Table 1. These results were mainly attributed to the successful PYT and TKG programs. However, certain troublesome aspects were encountered during program implementation. One of these problems is how best to handle the changing waste stream safely and economically. This is a key question facing decision makers. New products have significantly altered the composition of wastes and have demanded new techniques to properly control the hazards associated with their disposal. The role of the public in the decision-making process has also become a key concern in waste handling. Given the increased public interest in these activities which affect the environment and regulatory support for public involvement in environmental decision-making, the public has taken on the role of a "shadow regulator". Secondarily, for consolidating these programs, penalties are necessary to audit the public to prohibit illegal activities. For instance, local cities enforce mandatory sorting schemes, whereby citizens face penalties if they do not separate recyclables from the trash before pick-up. Currently, fines between US$52 and US$170 are imposed on illegal dumpers, and those counterfeiting the special trash bags will be fined between US$1000 and US$3300 and may be subject to criminal penalties.

Moreover, it is noted that any new strategy must consider its possible impact on related existing programs or objectives. A softer approach or step-by-step implementation is needed. To initiate these programs, the Taiwanese EPA has adopted a gradual procedure to eliminate the adverse impact upon the related industries, such as the plastic manufactory industry. For example, starting in July 2002, the EPA began the first stage targets for restricted use. The annual elimination rate of plastic shopping bags was 5%, and the annual reduction rate for plastic tableware was 3%. Starting in January 2004, the EPA began the second stage targets for the restricted use, in which the annual reduction rate of plastic shopping bags and plastic tableware was increased by 7% and 6%, respectively.

However, as discussed in Section 4.2, the concentration of plastic waste in MSW is not easily reduced, irrespective of the programs. According to the EPA's collected data on waste and 2002s GNP in Quarterly Report for Citizens' Economic Tendency (Taiwan EPA, 2005), the result from analyzing the relationship between the country's GNP and its average quantities of plastic waste shows that the USA is 2.0 g/US$ (grams of plastic waste generated for per dollar of GNP), Japan is 1.3 g/US$, France is 2.0 g/US$, Germany is 0.6 g/US$, England is 1.9 g/US$, South Korea is 5.1 g/US$, and Taiwan is 5.8 g/US$, which is the highest. Unfortunately, it is roughly estimated at 5.6 g/US$ in 2005 for Taiwan. This implies that these programs, especially RUP and PRP, must be checked and modified to reduce the percentage of plastic waste in MSW. Through program enforcement such as the restricted use of plastic shopping bags and plastic tableware, Taiwanese citizens will alter their living habits using plastic products and become socially and environmentally more aware. Thus, through the restricted use policy, the Taiwanese EPA will reform the habit of using plastic shopping bags and plastic tableware to gradually change people's disposal habits during consumption. The Taiwanese EPA will further review the living patterns of Taiwanese citizens to recycle other disposable articles during consumption, and expect the country to reach environmentally sustainable development.

Although program adoption and implementation has been conducted for a time, the characteristics of MSW going to the incinerator have changed and some obstacles were encountered and need to be solved. The Taiwanese government actively strives to establish more concrete policies and objectives, especially, understanding the support of the general public, the cooperation of private sectors,and the open-mindedness of the public sectors. The management strategy must be maintained in tandem with the global trend to achieve a zero-waste-discharge country. Therefore, the characteristics of the MSW going to the incinerator will change. Also, it is important to consider changes that may occur in the composition and characteristic of MSW over time in planning for future MSW management systems.

5. Conclusion

Programs involved in recent management strategies for MSW reduction and recycling have a significant influence on the physical composition of MSW, especially on the concentration of food waste, paper, and plastics. In 2003, paper or wood waste was typically the largest component of MSW; after the programs were initiated, plastic waste became the largest component of the MSW stream and is predicted to continue growing. The TKG and PYT programs can reduce the percentage of high-moisture food waste in MSW and lead to decreases in moisture content. In this work, we observed that the heating value of the MSW generated in Taiwan increased gradually by about 5% annually after program implementation. These programs encourage restaurants to increase food waste reduction efforts and cause local governments to strive to establish better relative programs for the collection and recovery of food waste in Taiwan. A comparison of the monthly variation of chemical elements indicates that carbon is the element with maximum variation among all elements in the organic compounds. The chlorine content in MSW changed, as a result of the reduction in usage of PVC plastic due to RFM and the reduction in food waste and salt content due to TKG. This achievement will lead to reduced dioxin emissions from MSW incineration. In other words, these new programs decrease the chlorine content in the waste and are actually good measures of reducing dioxin emission from MSW incinerators.

Although the adoption and implementation of these programs have been initiated, some obstacles were encountered and need to be solved. The Taiwanese government still actively strives to establish more concrete policies and objectives, in particular, understanding the support of the general public and the cooperation of private sectors, as well as the open-mindedness of the public sectors. The management strategy must be conducted in tandem with the global trend towards zero-waste-discharge. Therefore, it is important to consider the changes that may occur in the composition and characteristics of MSW over time, in planning for future MSW management systems. All programs related to MSW reduction management are noteworthy.

Acknowledgements

The authors are grateful to the National Science Council, ROC for the financial support of this work (Grant No. NSC-94-2211-E027-002).

References

Bébar, L., Martinák, P., Hájek, J., Stehlík, P., Hajný, Z., Oral, J., 2002. Waste to energy in the field of thermal processing of waste. Applied Thermal Engineering 22, 897–906.

Chang, Y.M., Chen, M.Y., 1993. Industrial waste to energy by circulating fluidized bed combustion. Resources, Conservation and Recycling 9 (4), 281–294.

Consonni, S., Giugliano, M., Grosso, M., 2005. Alternative strategies for energy recovery from municipal solid waste. Part B: emission and cost estimates. Waste Management 25, 137–148.

Dioxin, N., Langer, U., 2006. Development of a MSW classification system for the evaluation of mechanical properties. Waste Management 26, 220–232.

Ettouney, R.S., El-Rifai, M.A., El-Behairy, S.A., 2005. Control of thermally integrated incineration-waste heat recovery systems, a case study. Applied Thermal Engineering 25, 1195–1205.

Hallas-Burt, S., Halstead, J.M., 2004. Pay-as-you-throw trash pricing. Bio-Cycle 45 (9), 30–33.

Holmgren, K., Henning, D., 2004. Comparison between material and energy recovery of municipal waste from an energy perspective – a study of two Swedish municipalities. Resources, Conservation and Recycling 43, 51–73.

Kirkeby, J.T., Birgisdottir, H., Hansen, T.L., Chirstensen, T.H., Bhander, G.S., Hauschild, M., 2006. Evaluation of environmental impacts from munucipal sold waste management in the municipality of Aarhus, Denmark. Waste Management & Research 24 (1), 16–26.

Koufodimos, G., Samaras, Z., 2002. Waste management options in southern Europe using field and experimental data. Waste Management 22, 47–59.

Li, K., Huang, C., 2006. Integrated analysis of modern MSW management trend. In: Proceeding of the 99th Annual Conference and Exhibition of AWMA, 60–61, New Orleans, LA, USA, June 20–23.

Mrayyan, B., Hamdi, M.R., 2006. Management approaches to integrated solid waste in industrialized zones in Jordan. Waste Management 26, 195–209.

Petersen, C.M., Berg, E.O., Rönnegård, L., 2005. Quality control of waste to incineration – waste composition analysis in Lidköping, Sweden. Waste Management & Research 23 (6), 527–533.

Taiwan EPA, 2005. Annual Report of Natioal Sustainable Development. EPA Report No.1009102530.

Tchobanoglous, G., Theisen, H., Vigil, S., 1993. Integrated Solid Waste Management. McGraw-Hill, New York.

Thipse, S.S., Sheng, C.M., Booty, R., Magee, R.S., Bozzelli, J.W., 2002. Chemical makeup and physical characterization of a synthetic fuel and methods of heat content evaluation for studies on MSW incineration. Fuel 81, 211–217.

Williams, P., 1998. Waste Treatment and Disposal. John Wiley & Sons, Inc., New York.

Wu, X.Y., Huang, G.H., Liu, L., Li, J.B., 2006. An interval nonlinear program for the planning of waste management systems with economies-of-scale effects. European Journal of Operational Research 171, 349–372.

Yeomans, J.S., Huang, G.H., 2003. An evolutionary grey, hop, skip and jump approach: generation alternative policies for the expansion of waste management. Journal of Environmental Informatics 1 (1), 37–51.