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Comparative evaluation of RDF and MSW incineration

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Abstract

In the last few years, a number of credible surveys have shown that material recycling and incineration processes appear to work well together in an integrated system. Compatibility exists for several reasons related to not only economic and environmental, but also political and social aspects in several developed countries. However, the impacts of solid waste presorting on incineration facilities remain unclear in developing countries due to the inherent complexity of solid waste composition. This analysis evaluates the comparative effects by burning municipal solid waste (MSW) and refuse-derived fuel (RDF) in the same incinerator. The solid waste presorting or RDF production process consists of standard unit operations of shredding, magnetic separation, trommel screening, and air classification. The production of RDF and collected MSW are dedicated to a small scale incinerator. Focus has been placed upon the comparative evaluation of heat balance, ash property, and the quality of flue gas in the incineration process. It appears that the incineration of RDF presents relatively better performance in several aspects. © 1998 Elsevier Science B.V.

Keywords: Incineration; Refuse-derived fuel; System evaluation; Solid waste management

1. Introduction

The rising prices of raw materials and the depletion of landfill space have resulted in an increasing concern for material recovery and reuse. On the other hand, thermal treatment by using incineration technology has been proven as an attractive method of waste disposal for many years due to the primary advantages of hygienic control, volume reduction, and energy recovery. But previous experience in the solid waste management has been that solid waste presorting prior to incineration is solely a function of material recycling. This assumption would result in difficulties to justify the

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economic feasibility due to the instability in the secondary material market. In recent years, the focus has been changing in response to increasing public and environmental concerns with incinerator emissions and ash properties. Recognition of the integrated value of solid waste presorting to the incineration process would present a new perspective in solid waste management. Such a new perspective may include the coordination of environmental benefits from solid waste presorting, improved incinerator performance, and the direct revenues from recycled materials.

In the last decade, a number of credible research regarding material recovery from solid waste streams were carried out in many European countries and the USA [1–3]. The advances of thermal treatment of refuse-derived fuel (RDF) started to receive wide attention in later periods [4]. But the impact of solid waste presorting on incineration facilities remain uncertain, which motivates a lot of research activities. Valuable engineering tests were conducted for the understanding of emissions and ash characteristics by burning RDF as fuel in the mass burn [5–8] or fluidized bed [9,10] incineration systems. In addition, the feasibility of pyrolysis and bioconversion of RDF were evaluated for various purposes of end-product recycling [11,12]. Comparative studies of hazardous waste were presented as well based on different types of incinerators [13].

Although Taiwan has set a bold agenda of solid waste incineration programs to conserve the landfill space in the last few years, the continuing increase of heating value and the promotion of waste recycling activities has never been tempered. At least two proposals for planning the additional municipal solid waste (MSW) presorting process prior to the large scale municipal incinerators, located in the City of Tai-Chung and the County of Taipei, have been raised in 1996. The integrated system configuration with the MSW presorting and incineration units has also been considered for several modular incinerators in the planning stages, that are to be located in several rural areas in Taiwan. However, the impacts of solid waste presorting on incineration process remain unclear due to the higher moisture and plastics content in the solid waste streams in Taiwan, which characteristics are not fairly representative for most countries.

This analysis evaluates the comparative effects by burning MSW and RDF in the same incinerator. The solid waste presorting or RDF production process consists of standard unit operations of shredding, magnetic separation, trommel screening, and air classification. The production of RDF is dedicated to a small scale incinerator. A series of sampling and analysis programs were conducted and the performance of burning RDF and MSW was comparatively characterized such that subsequent economic and technical feasibility studies would become feasible. Focus has been placed upon the comparative evaluation of heat balance, ash property, and the quality of flue gas in the incineration process, using MSW and RDF as fuels, that would serve as the analytical basis in the future engineering projects.

2. Facility description

2.1. Solid waste presorting system

As is illustrated in Fig. 1, the designed solid waste presorting process consists of three major units: shredding, air classification, and screening. The facility may process

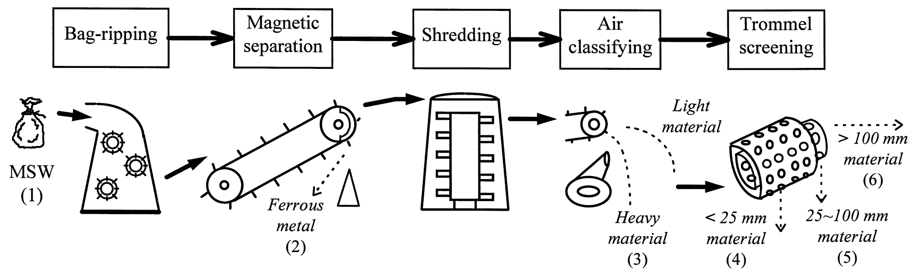

Fig. 1. System configuration of the solid waste presorting process.

30 t/h at maximum capacity per one line. The MSW is delivered to the facility by packer trucks. Bag-ripping unit, in charge of opening these plastic bags, initializes the presorting process. Ferrous metal is extracted from the MSW stream by using magnets after the bag-ripping unit. Recovered ferrous metal is conveyed to a ferrous storage bin from where it will be recycled. MSW is then shipped into a vertical hammermill shredder through a belt-type conveyor that is followed by an air classifier. Non-ferrous materials, such as aluminum can and other combustibles, as well as the MSW are crushed by the vertical hammermill shredder. However, a manual sorting unit or eddy current separator could be added prior to the vertical hammermill shredder for the recovery of aluminum cans in the future.

The air classifier, blowing with a regular air stream of 200 m^3/min from the vertical hammermill shredder, further isolates and separates the inert materials, such as glass, ceramics, and so on, to reduce the content of heavy material in the residual MSW streams. Light materials, passing through the air classifier, are sent into the trommel screen for advanced separation. The dimensions of the openings on the surface of trommel screen can be varied to fine-tune the processing function and assure maximum combustibles recovery. The trommel is thus designed as a two concentric shell. The outer shell, which is 2.33 m in diameter and 4.3 m in length, has many circular holes on the surface which is designed to remove the shredded materials smaller than 25 mm. The inner shell, which is 1.9 m in diameter and 4.56 m in length, separates partial waste stream with the size of between 25 and 100 mm. Three waste streams can be further classified in which two of them are trommel undersize. In other words, particle size is controlled by the openings design on the surface of the trommel such that the material with the particle size less than 25 mm (trommel underflow) and the particle size between 25 mm and 100 mm (trommel middle flow) are separately arranged by two different sets of openings with a concentric shell configuration. The overflow, passing through this trommel screen, would present the most light portion in the MSW with the size greater than 100 mm (trommel overflow), and can be exactly identified as the fluff-RDF in the end product of this sorting process. However, both outputs with particle size larger than 100 mm and between 25 mm and 100 mm can be used as alternative fuels in the incineration facilities.

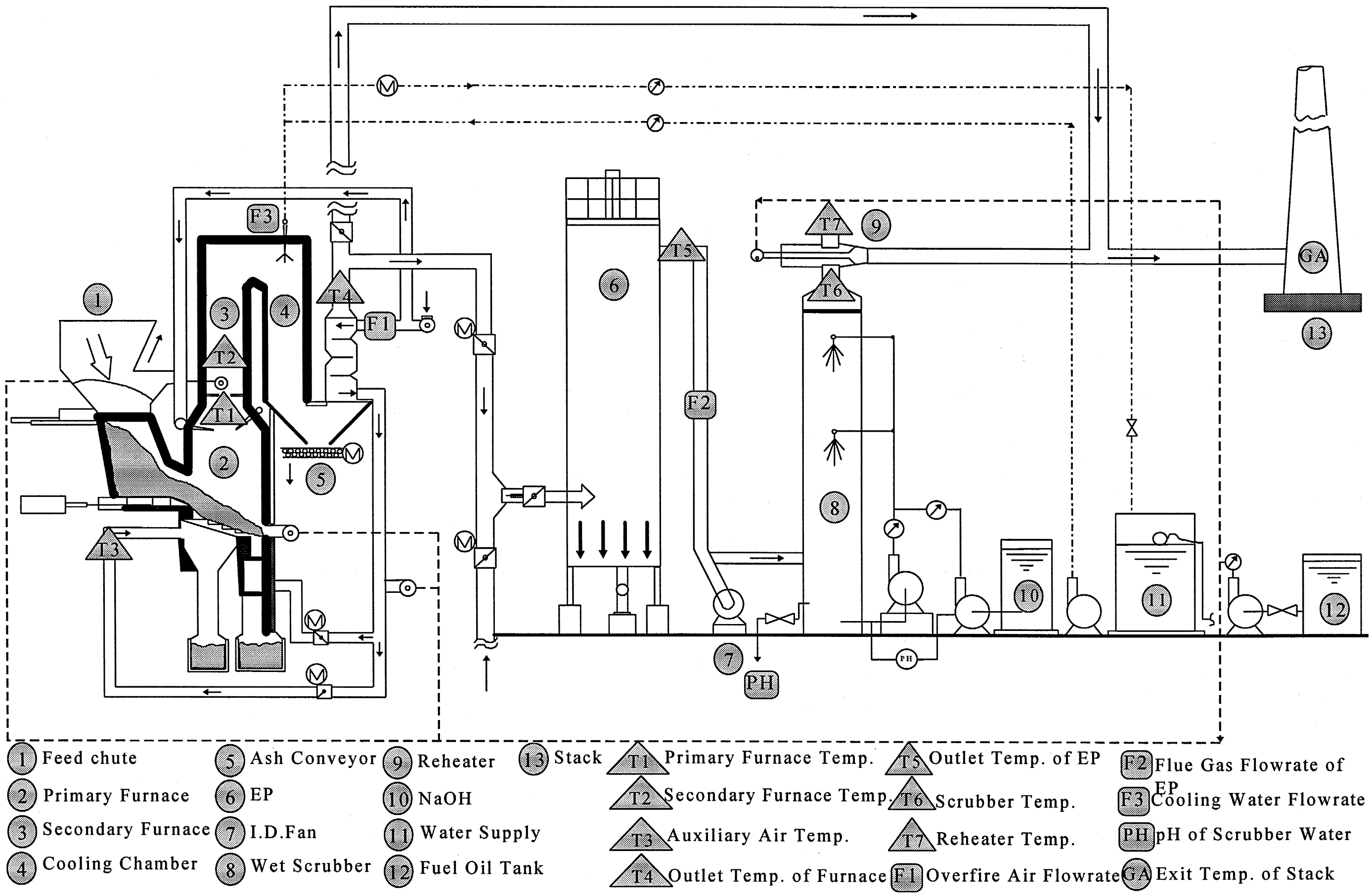

Fig. 2. System configuration of the solid waste incineration process.

2.2. Solid waste incineration system

Fig. 2 presents the system configuration of the modular incinerator. The plant is installed with a capacity of 0.8 t/day in one line. From the silo the RDF or MSW is fed into the furnace where the combustion takes place on a 3-step movable grate system. The flue gases generated pass through the first furnace and is cooled down at the outlet of secondary furnace. The heat exchanger is installed at the outlet of secondary furnace for the preheating of auxiliary air. The flue gases are eventually led through air pollution control system, consisting of a conventional electrostatic precipitator (EP) followed by a wet scrubber. Reheater is prepared for the prevention of flue gas emissions with higher moisture content.

Table 1
The average of the sample property of MSW and RDF

	MSW	RDF	
		25–100 mm	> 100 mm
Bulk density (kg/m^3)	289.9	334.8	179.1
Paper (%)	28.62	8.08	5.70
Plastics (%)	26.33	29.15	57.81
Garden trimmings (%)	4.05	4.60	4.21
Textiles (%)	9.03	7.43	18.23
Food waste (%)	14.04	0.00	0.00
Leather/rubber (%)	0.58	1.13	1.48
Metal (%)	6.99	1.09	0.03
Glass (%)	7.26	0.00	0.00
Ceramics and china	0.47	0.00	0.00
< 5 mm (%)	1.59	16.15	8.89
> 5 mm (%)	1.04	32.36	3.65
Heat value			
HHV (kcal/kg)	2277.8	2554.5	3715.9
LHV (kcal/kg)	1816.3	2095.7	3296.0
Chemical composition (on wet basis,%)			
C (%)	20.11	24.45	29.24
H (%)	2.92	3.21	3.30
N (%)	0.55	1.09	1.04
Cl (%)	0.18	0.16	0.23
S (%)	0.80	0.10	0.05
O (%)	12.58	11.69	15.90
Proximate analysis (on wet basis, %)			
Moisture (%)	50.65	47.55	40.28
Ash (%)	12.21	11.75	9.96
Combustibles	37.15	40.70	49.76

3. Preparation of RDF

Considerable amount of MSW in Tainan County was collected, and the testing of the solid waste presorting process was proceeded in December, 1995. 13 samples were collected at the locations of (1) and (6), while 15 samples were collected at the locations of (3)–(5) in Fig. 1. The heat value, physical, approximate analysis, and ultimate analyses for both RDF and MSW were also established, and the results are presented in Table 1.

It shows that the plastics content dramatically increase from 26.33% in the MSW to 67.81% in the trommel overflow at dry basis. On the other hand, food waste, metal, glass, and ceramics were almost reduced to zero in the trommel overflow. The moisture content was decreased from 50.65% in the MSW to 40.28% in the trommel overflow. This is due to the evaporization effect during the air classification process. The combustible content was increased from 37.15% in the MSW to 49.76% in the trommel overflow. Similarly, the combustible content was increased from 20.11% in the MSW to 29.24% in the trommel overflow. In addition, the contents of chlorine and sulfur would be the major elements for the examination of the impact on air pollution control. It is observed that the sulfur content was decreased from 0.8% in the MSW to 0.05% in the products of trommel overflow. But the chlorine content was slightly increased from 0.18% in the MSW to 0.23% in the products of trommel overflow. This is probably due to the increase of plastic bags in the trommel overflow. However, the high heating value was increased from 2277 kcal/kg in the MSW to 3715 kcal/kg in the trommel overflow. An increase of almost 66% of high heating value in the RDF products would result in a higher degree of energy recovery if a waste-to-energy facility is installed.

4. Comparative evaluation

Separation of valuable constituents is accomplished by various mechanical, magnetic or aerodynamic separation techniques in the presorting system. Table 2 illustrates the

Table 2
The operating condition of incineration process

	MSW		RDF	
	Range	Average	Range	Average
T1 (°C)	691–874	806.6	825–934	879.8
T2 (°C)	928–1044	1001.3	1007–1062	1033.8
T3 (°C)	170–233	219.6	214–235	228.4
T4 (°C)	269–290	279.4	268–288	271.8
T5 (°C)	110–206	184.5	176–200	191.1
T6 (°C)	55–72	67.1	61–66	63.8
T7 (°C)	142–154	148.8	144–155	150.4
F1 (m^3/h)	0.04–4.4	3.03	3.44–4.76	4.27
F2 (m^3/h)	6.06–9.3	8.19	6.27–9	7.50
F3 (m^3/min)	0.65–0.7	0.67	0.08–4.14	0.68
pH	6.5–9.7	8.09	5.8–9.3	7.68
GA (°C)	114–132	126.2	124–133	128.3

Table 3
The analysis of flue gas

	MSW	RDF	Standards
Particulate (mg/Nm^3)	5.7	3.15	220
CO_2 (%)	6.65	7.9	
CO (ppm)	321	203	350
O_2 (%)	12.0	11.2	
H_2O (%)	26.6	14.1	
SO_x (ppm)	13.5	15.0	300
NO_x (ppm)	18.0	9.2	250
HCl (ppm)	0.36	0.58	7
Pb (mg/Nm^3)	0.13	0.013	0.7
Cd (mg/Nm^3)	ND < 0.003	0.0095	0.7
Hg (mg/Nm^3)	10	5.35	60

operating conditions of both MSW and RDF incineration processes. Auxiliary fuel is used to ensure the temperature of flue gas is over 1000°C in the secondary furnace for the minimization of dioxin/furan emissions. The temperature of flue gas down stream of the heat exchanger is reduced to 180–190°C by means of water cooling and air preheating. The operation of wet scrubber would reduce the temperature of flue gas to 65°C. Reheater installed before the stack is used to increase the flue gas temperature above 150°C.

Table 3 presents the analytical results of the quality of flue gases. The use of EP is particularly effective. Residual dust level of < 10 mg/Nm^3 at 11–12% O_2 can be attained. All metal emissions are relatively less than the control standards. There is no standard NO_x control system. But the NO_x emission in the flue gas is extremely lower than the control standard. The emission levels of acid gases in the stack are all below the permitted levels. In general, from a perspective of the quality of flue gases, RDF has presented relatively higher advantages over MSW.

Samples of fly ash and bottom ash were analyzed in accordance with the Toxicity Constituents Leaching Procedure (TCLP). Tables 4 and 5 list the analytical results of

Table 4
The analysis of bottom ash

	MSW	RDF	TCLP Standards
Pb (mg/l)	ND < 0.03	0.12	5.0
Cd (mg/l)	0.02	0.06	1.0
Cu (mg/l)	0.33	0.39	15.00
Zn (mg/l)	1.6	16	25.00
Cr (mg/l)	0.03	0.12	5.0
Hg (mg/l)	ND < 0.0002	ND < 0.0002	0.2
As (mg/l)	ND < 0.001	ND < 0.001	5.0
pH	11.8	10.2	
Cr^{6+} (mg/l)	0.006	0.05	2.5
CN^- (mg/l)	ND < 0.002	ND < 0.002	
Carbon Content (%)	2.65	0.65	

Table 5
The analysis of fly ash

	MSW	RDF	TCLP Standards
Pb (mg/l)	9.6	0.04	5.0
Cd (mg/l)	4.6	2.6	1.0
Cu (mg/l)	22	9.6	15
Zn (mg/l)	5.3	21.7	25
Cr (mg/l)	ND < 0.02	0.04	5.0
Hg (mg/l)	ND < 0.0002	ND < 0.0002	0.2
As (mg/l)	ND < 0.001	ND < 0.001	5.0
pH	5.6	5.00	
Cr^{6+} (mg/l)	0.003	0.002	2.5
CN^{-} (mg/l)	0.002	ND < 0.002	

TCLP tests for both bottom ash and fly ash. The leachability of regulated heavy metals is affected by waste composition, its combustion history, and handling method. The leaching test of bottom ash revealed that both types of bottom ash generated from burning MSW and RDF cannot be classified as hazardous materials. However, it is found that the extracted metals from the bottom ash of RDF burning exhibit relatively higher concentrations. This is probably due to the higher percentages of paper content with printing ink in the RDF product. Table 5 shows that extractable cadmium

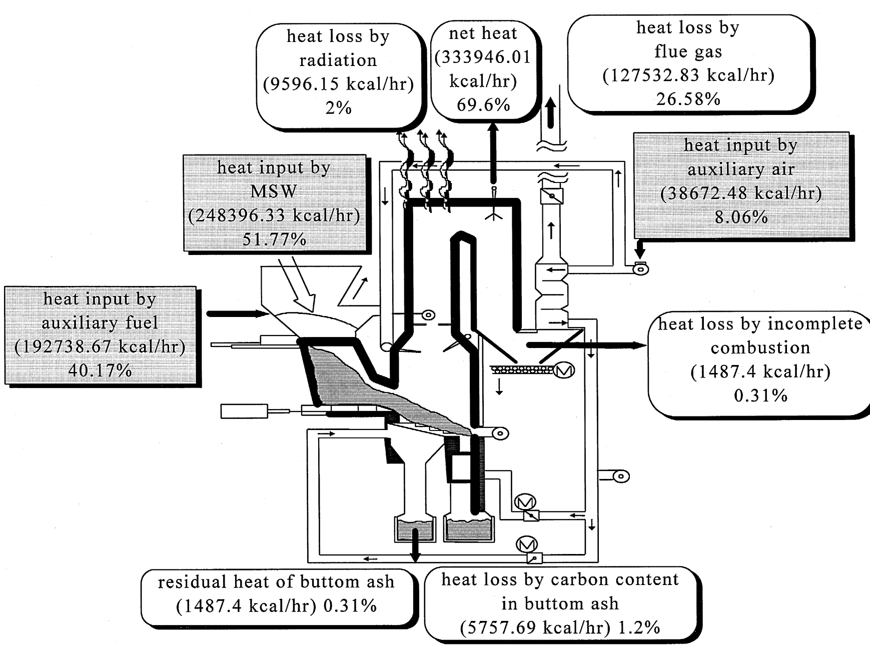

Fig. 3. Heat balance of the MSW incineration process.

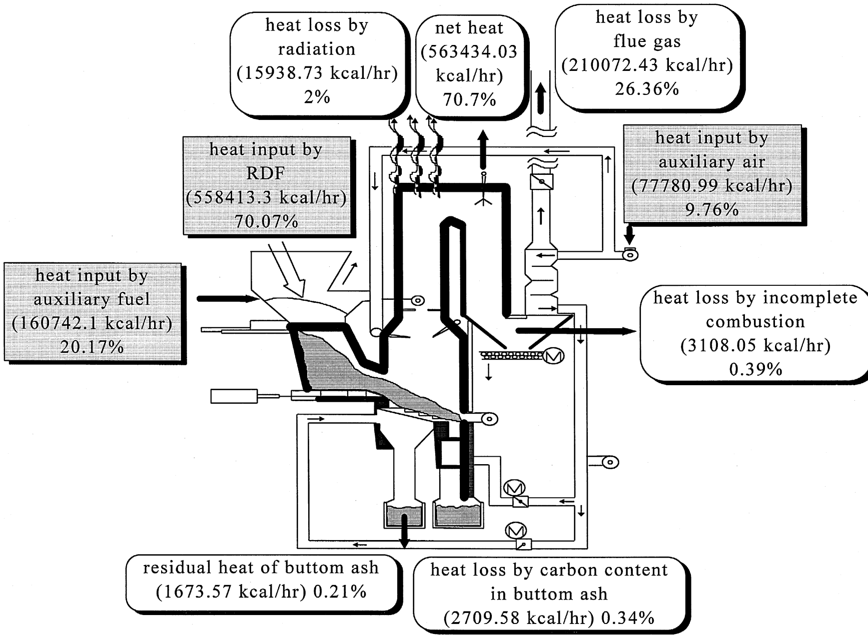

Fig. 4. Heat balance of the RDF incineration process.

concentrations in both types of fly ash are far beyond the regulatory levels. This substantial difference would make the fly ash subject to post-treatment requirements. In general, the extracted metals from the fly ash in the RDF incineration process exhibit relatively lower concentrations.

5. Further remarks

Figs. 3 and 4 further illustrate the information of heat balance for both scenarios in the incineration process. In addition, Figs. 5 and 6 summarize all the related performance tests in this analysis. Overall, the presorting system may generate RDF product with a more uniform chemical and physical characteristics as well as high heating value products; and resource recovery prior to incineration has significant advantages such as reduced amount of ash, less residual carbon contents in both flue gas and ash, and lower toxic and hazardous emissions. To promote a valuable resource recovery program in a solid waste management system, the variations of waste composition, prices of recyclables in the secondary material market, and the related costs incurred for building the presorting system must be taken into account simultaneously. However, traditional economic trade-offs among waste recycling and energy recovery exists in the optimization process.

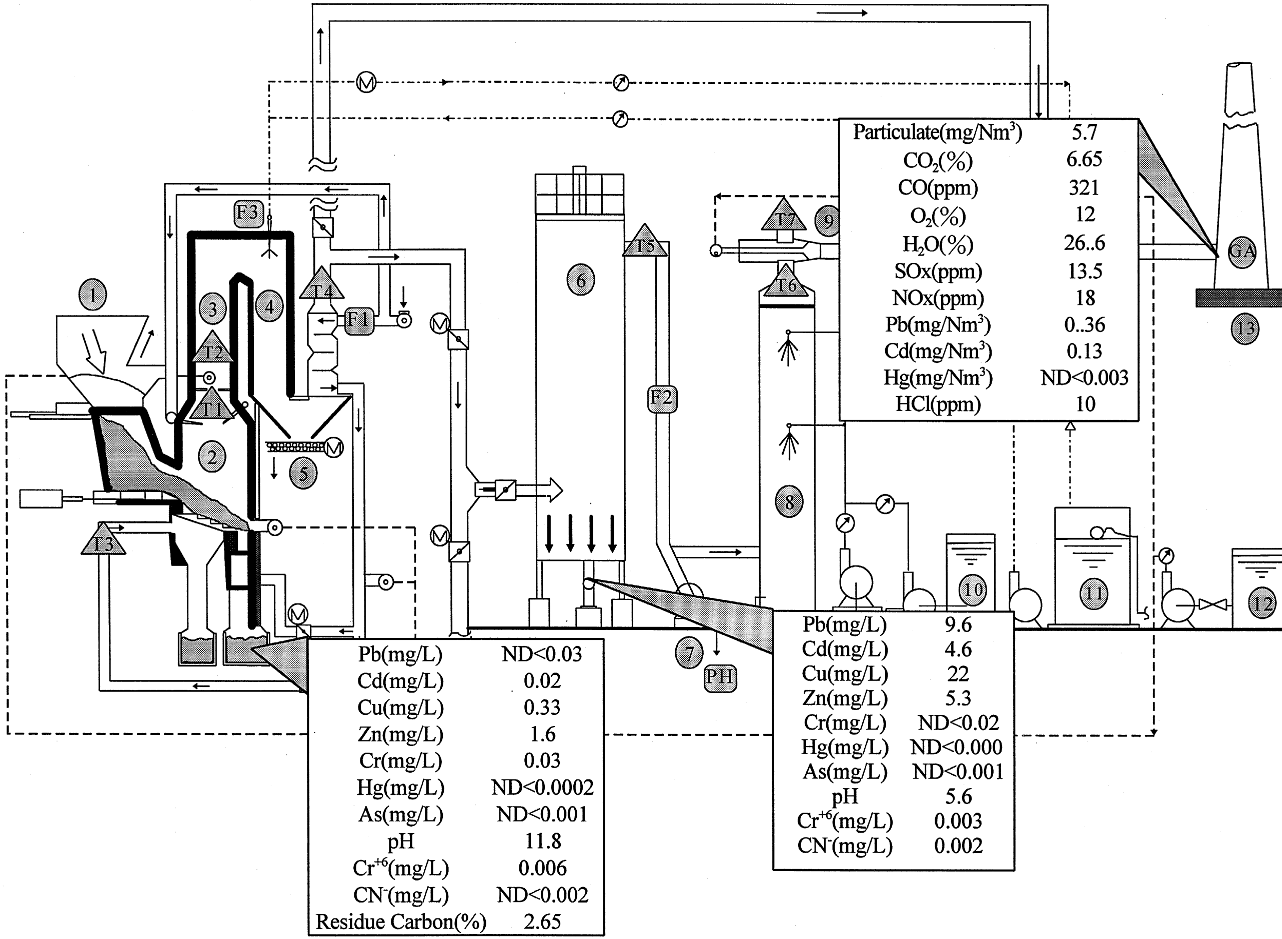

Fig. 5. Summary of the performance test of the MSW incineration process.

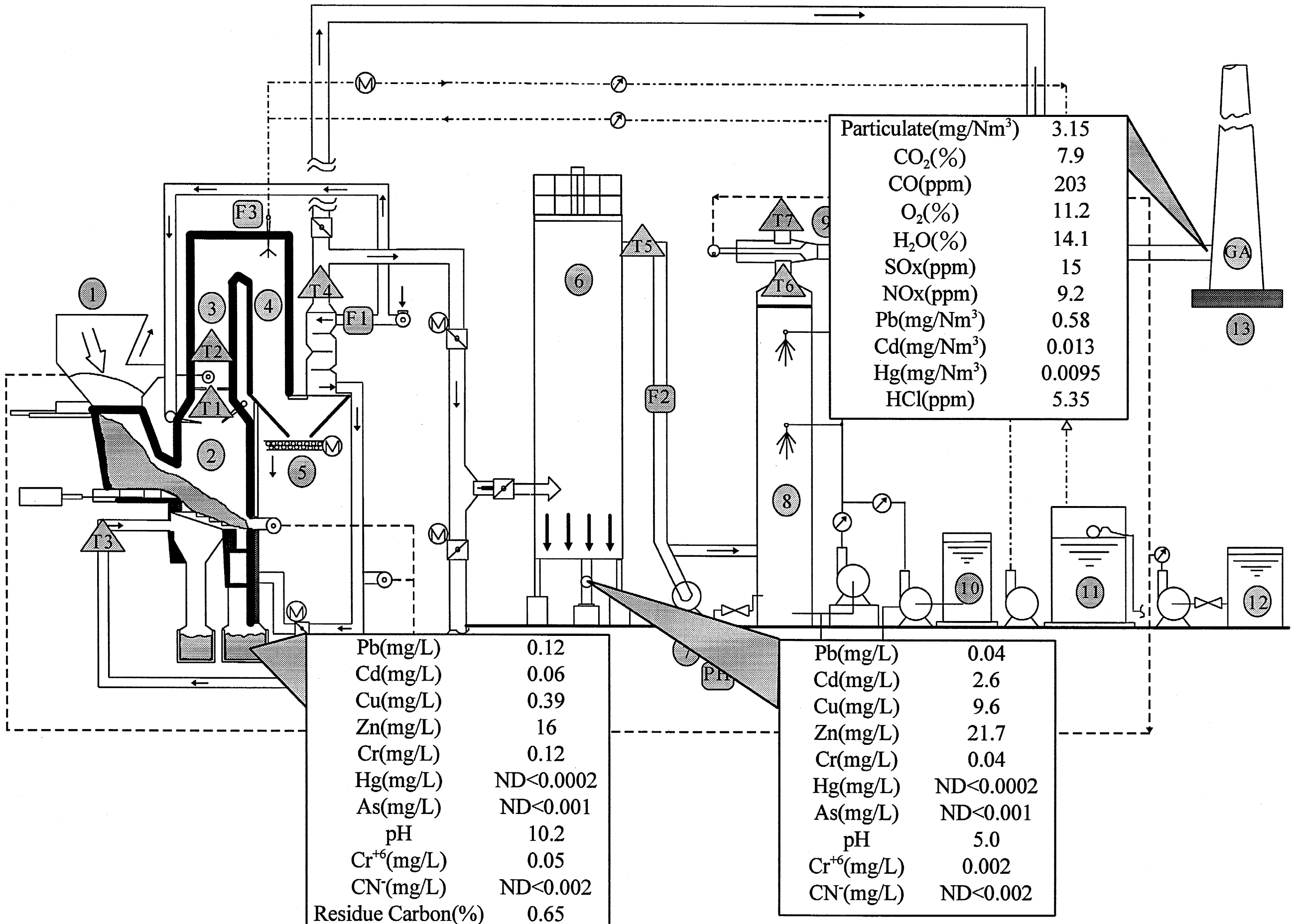

Fig. 6. Summary of the performance test of the RDF incineration process.

6. Conclusion

According to the official record of the Environmental Protection Administration (EPA) in Taiwan, over 9 million tons of municipal solid waste have been generated in 1995. Effective management of solid waste streams is a substantial challenge in current solid waste management systems because of their complexity during the coordination of various management strategies. As a consequence, the development of integrated technologies for resource recovery, recycling, and reuse becomes a central focus in the successful solid waste management program. Incineration technology has been recognized as an effective alternative for solid waste management in the urban and suburban areas with limited landfill space. Mass burn of MSW typically entails collection of garbage, separating the bulky waste and burning it on a mechanical grate system. All contents of recyclables, such as glass bottles, newspapers, tin cans, batteries, and plastic bags, are passed through the furnace and into the flue gases or ash. Resource recovery is usually limited to separating ferrous metal objects from the bottom ash after combustion. It is believed that the use of a presorting system as part of the incineration facilities may reduce substantial potentials of hazards while burning the solid waste as fuels.

This paper specifically investigates such potential benefits for mass burn incineration using RDF as fuel. Test results indicate that mass burn of MSW may result in a lower average heating value of the waste stream destined for incineration, a higher possibility of toxic substance emissions due to incomplete combustion, and a lower energy recovery potential, compared to the use of RDF as fuels. The inclusion of waste presorting in the incineration facilities can provide RDF with better quality to the mass burn process. It is expected that not only heavy metals in the fly ash may be significantly reduced but better quality of flue gases may be attained. With higher heating value in the RDF product, better efficiency of energy recovery could also be achieved from engineering perspectives.

Acknowledgements

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