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Experimental study on MSW gasification and melting technology

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Abstract

In order to develop municipal solid waste (MSW) gasification and melting technology, two preliminary experiments and a principle integrated experiment were fulfilled respectively. The gasification characteristics of MSW were studied at 500–750°C when equivalence ratio (ER) was 0.2–0.5 using a fluidized-bed gasifier. When temperature was 550–700°C and ER was 0.2–0.4, low heat value (LHV) of syngas reaches 4000–12000 kJ/Nm^3. The melting characteristics of fly ash were investigated at 1100–1460°C using a fixed-bed furnace. It was proved that over 99.9% of dioxins could be decomposed and most heavy-metals could be solidified when temperature was 1100–1300°C. The principle integrated experiment was carried out in a fluidized-bed gasification and swirl-melting system. MSW was gasified efficiently at 550–650°C, swirl-melting furnace maintains at 1200–1300°C stably and over 95% of fly ash could be caught by the swirl-melting furnace. The results provided much practical experience and basic data to develop MSW gasification and melting technology.

Key words: municipal solid waste (MSW); fluidized-bed gasification; swirl-melting; characteristics

Introduction

With expanding population of China, yields of municipal solid waste (MSW) increases sharply in recent twenty years and now reaches over 150×10^6 t/a (National Bureau of Statistics of China, 2005), as displayed in Fig.1. It is reported that about 2/3 of cities are surrounded by MSW, and many environmental problems have been caused in China, including pollution of water sources and soil, emission of green house gas, epidemic disease, etc. (Nie, 2000). It is urgent to find a suitable way to efficiently dispose MSW.

Gasification and melting technology are considered to be an efficient means to dispose MSW with less emission. Especially, it can sharply reduce emission of dioxins and heavy metals, which are strongly concerned by public when MSW is combusted (Hu *et al*., 2006; Wang *et al*., 2006; Suzuki and Takahashi, 2002; Shohichi and Morihiro, 2002; Si *et al*., 2006; Guan and Peart, 2006; Li *et al*., 2006; Yan *et al*., 2006). Several gasification and melting processes have been proposed and industrialized in developed countries. For example siemens/KWU process, which consists of a rotating pyrolysis drum heated indirectly by flue gas and a melting furnace at 1250–1400°C (Kawai *et al*., 2000). Thermoselect process, it consists of a degasification channel heated indirectly by hot medium, an oxygen-blown gasification and fixed-bed melting furnace at about 2000°C (Calaminus and Stahlberg, 1998); Von Roll RCP process: it consists of an oxygen-blown grate-type gasification chamber and an oxygen-blown combustion and melting furnace at 1400°C (Malkow, 2004), and direct-melting process: gasification and melting are completed in a single furnace with rich-oxygen-air blowing (Shohichi and Morihiro, 2002), etc. However, there is no report about application of MSW gasification and melting technology in developing countries.

Many valuable researches of this area have been reported in China. Liu *et al*. (1999) compared various technologies of MSW disposal, and considered thermal technology was potential in China. Ni *et al*. (2006), Xiao *et al*. (2006a; 2007) studied the gasification characteristics of components in MSW and concluded that organic components could be gasified efficiently at 500–700°C. Chi *et al*. (2005) and Xiao *et al*. (2005) researched the characteristics of HCl emission when MSW was combusted/gasified, and considered that it could be eliminated using additives at 500–650°C. Li (2002), Jin *et al*. (2005), and Jiang *et al*. (2006) investigated the characteristics of dioxins and heavy metals when fly ash was melted and find it is an efficient

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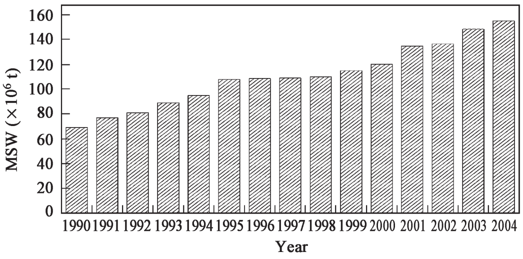

Fig. 1 Amount of municipal solid waste (MSW) in China.

way to control dioxins and heavy metals.

On the basis of these researches, two preliminary experiments and a principle integrated experiment were designed and fulfilled systemically in this study. It hopes to facilitate the development of MSW gasification and melting technology in China.

1 Methods and materials

1.1 Gasification experiments

MSW was simulated according to the average proportion of organic components (dry basis) in actual MSW of China (Xiao, 2006b), and it was used as materials of experiments, as shown in Table 1.

Table 1 Characteristics of simulative MSW for gasification

Organic components (%)					Low heat value (kJ/kg)
Kitchen garbage	Plastic	Wood and yard waste	Paper	Textile	
61	20	10	8	1	17960

The experiments of MSW gasification were carried out at a fluidized-bed gasifier, as displayed in Fig.2. The fluidized-bed gasifier is made of stainless steel tube with 4000 mm in height and 100 mm inside diameter, which is heated by hot flue gas from oil combustion chamber. The hot flue channel is made of homocentric stainless steel tube with 150 mm inside diameter. MSW is fed by a screw which locates 500 mm above the air distributor. The temperatures of dense part and sparse part of the gasifier are detected by K-type thermocouples, which locate 350 mm and 2000 mm above the air distributor respectively. Air is preheated in the oil combustion chamber and sent into the gasifer through the air distributor. Sand, which is 0.7–1.0 mm diameter, is acted as bed materials. The sampling point of syngas located after the cyclone. The analysis system consists of a filter, an accumulative flow-meter, a sampling pump, and a gas chromatography. The gas chromatography (GC9890A) is provided by Renhua Gas Chromatography Exploitation and Application Center of Nanjing, China. H_2, N_2, CO, CO_2 and CH_4 are detected by two thermal conductivity detectors (TCD) using argon as carrying gas at 60°C; C_2H_4, C_2H_6, C_3H_8, C_4H_{10} etc. are detected by a flame ionization detector (FID) using N_2 as carrying gas at 200°C.

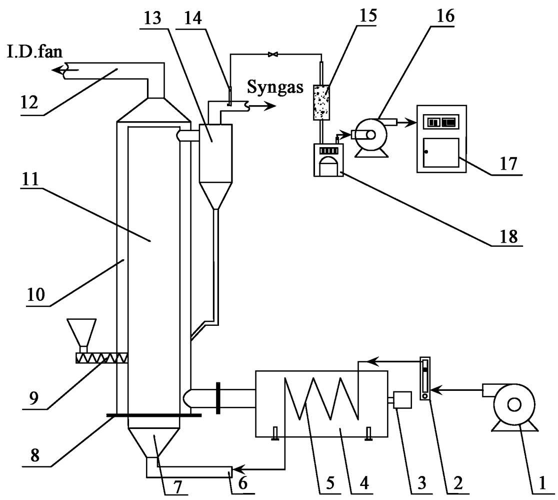

Fig. 2 Illustration of fluidized-bed gasifier. (1) F.D. fan; (2) flow meter; (3) oil burner; (4) combustion chamber; (5) air preheater; (6) inlet of fluidizing wind; (7) wind box; (8) air distributor; (9) feeding system; (10) hot flue channel; (11) fluidized-bed gasifier; (12) outlet of hot flue; (13) cyclone; (14) sampling point; (15) filter; (16) sampling pump; (17) syngas analyzer; (18) accumulative flow-meter.

1.2 Melting experiments

Fly ash involves in the melting experiments was obtained from a MSW combustion plant of Zhejiang Province, China, and the characteristics are displayed in Table 2.

Table 2 Characteristics of fly ash (%)

SiO_2	Al_2O_3	CaO	TiO_2	Fe_2O_3
17.66	3.94	34.79	2.66	12.04
CuO	$ZnCl_2$	ZnO	P_2O_5	K_2S
8.11	12.04	0.91	0.50	7.37

The melting experiments were carried out in a fixed-bed furnace of 600 mm in height and 100 mm inside diameter, as shown in Fig.3. It is equipped with an electric heating system (12 kW) and a B-type thermocouples to control temperature in range of 400–1600°C. In experiments, the furnace was maintained at designed temperature, and samples were sent into the furnace quickly; after 60 min, melted slag was moved out. Slag was grained and dissolved firstly, and then wait is analyzed by an atomic absorption spectrophotometer and Finngan Voyager mass spectrometer (LRMS) with a gas chromatograph (HRGC)

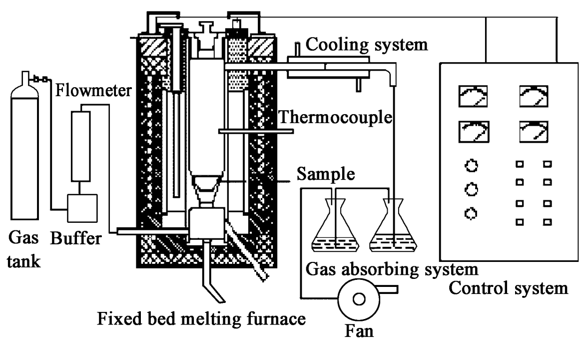

Fig. 3 Illustration of fixed-bed melting furnace.

to detect heavy metals and dioxins respectively. The experiments of dioxins were performed by the State Key Laboratory of Clean Energy Utilization, Zhejiang University, all isotope standards were purchased from Wellington laboratories, Canada or Cambridge Isotope Laboratory, USA. The toxicity was transformed into toxicity equivalence factor-value (TEF)-values according to the USEPA method 8280B.

1.3 Principle integrated experiments

On the basis of the characteristics of MSW of China, raw materials of the principle integrated experiment were prepared as shown in Table 3.

The principle integrated experiments were carried out using a fluidized-bed gasification and swirl-melting system, which contains two main parts, as shown in Fig.4. One is a gasifer, which is the same to the fluidized-bed gasifier mentioned above. The other is a swirl-melting furnace, which is made of a corundum tube with 1500 mm in height and 300 mm inside diameter. A B-type thermocouple locates 400 mm below the inlet of syngas. Melting slag exits from the bottom of the furnace, and drops into a quenching pool. The exit of flue gas locates about 1000 mm above the quenching pool. After a sampling point, flue gas is introduced into a scrubber and discharged from the stack. Syngas was analyzed as the methods above, and flue gas is detected by SAE-19 type analyzer, which was provided by MRU Corp. German.

Table 3 Characteristics of MSW (dry basis) for principle integrated experiments

Components (%)						Low heat value (kJ/kg)
Kitchen garbage	Plastic	Wood and yard waste	Paper	Textile	Ash	
48.8	16.0	8.0	6.4	0.8	20	14368

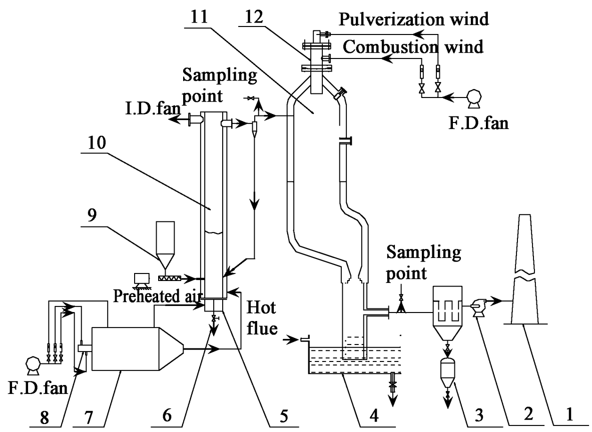

Fig. 4 Illustration of fluidized-bed gasification and swirl-melting system. (1) stack; (2) I. D. fan; (3) scrubber; (4) quenching pool; (5) wind box; (6) exit of slag; (7) combustion chamber; (8) oil burner; (9) feeding system; (10) fluidized-bed gasifier; (11) swirl-melting furnace; (12) oil burner.

2 Results and discussion

2.1 Analysis of gasification experiments

For avoiding over oxidation of metals in MSW, temperature of the gasification should be controlled below 700°C (Suzuki and Takahashi, 2002; Shohichi and Morihiro, 2002; Si *et al.*, 2006; Guan and Peart, 2006). To facilitate MSW gasification smoothly, temperature should be maintained over 500°C (Ni *et al.*, 2006; Xiao *et al.*, 2006a, 2006b, 2007), or the reactants will jam the gasifier. In this study, the flux of preheated air was adjusted in the range of 6–10 Nm^3/h and MSW was fed at rate of 2–6 kg/h. MSW was gasified at 500–750°C when ER was 0.19–0.5. The syngas was collected by a gasbag and analyzed by a gas chromatography. The results are displayed in Table 4.

H_2, CH_4, CO, C_2H_4 and other C_nH_m are the main contributing components in syngas, which determine low heat value (LHV) of syngas, which is an important parameter for gasification. Generally, LHV of syngas increases with increasing temperature or decreasing ER. When temperature is about 500°C and ER ranges from 0.2 to 0.4, LHV of syngas lies in range of 2800–4200 kJ/Nm^3. While when temperature is 550–700°C and ER ranges from 0.2 to 0.4, LHV of syngas reaches about 4000–12000 kJ/Nm^3. It seems that higher temperature facilitate enhancement of LHV. When ER ranges from 0.38 to 0.5, LHV of syngas is obviously lower than that when ER is 0.19–0.29; when ER is lower than 0.15, gasification can hardly completed in time and the gasifier will be jammed by reactants. Theoretic estimation indicates that it is enough to facilitate

Table 4 Experimental results of MSW gasification

Feeding rate of MSW (kg/h)	Flux of air (Nm^3/h)	ER of gasification	Temperature of gasification (°C)	Temperature of preheated air (°C)	Main components of syngas									LHV of syngas (kJ/Nm^3)
					CO_2	H_2	N_2	CH_4	CO	C_2H_4	C_2H_6	C_3H_8	C_4H_{10}	
2.3	6	0.50	720	352	8.9	3.6	68.4	2.6	6.5	3.24	0.11	0.06	0.23	4459
			620	283	11.2	2.0	69.8	1.4	6.6	1.43	0.10	0.01	0.13	2611
			493	290	12.8	1.4	70.5	0.8	4.8	1.11	0.12	0.03	0.22	2088
3	6	0.38	705	352	12.4	4.2	59.6	3.8	8.6	3.89	0.12	0.05	0.45	5883
			602	296	14.5	2.5	66.8	1.8	8.0	2.16	0.16	0.02	0.36	3786
			507	281	14.8	1.5	67.9	0.9	5.0	1.58	0.17	0.05	0.42	2743
4	6	0.29	687	352	15.6	5.8	48.2	4.6	9.1	5.91	0.71	0.10	1.41	9237
			593	307	14.1	2.7	65.3	1.5	6.0	2.17	0.25	0.05	0.63	3849
			516	282	16.0	1.1	69.3	0.8	5.3	1.63	0.21	0.07	0.33	3308
6	6	0.19	691	352	15.1	5.4	44.3	5.7	10.2	7.87	0.99	0.14	2.10	11958
			593	308	15.5	3.3	60.3	2.2	8.1	3.20	0.43	0.09	0.94	5588
			507	279	14.2	4.1	61.6	1.8	9.5	1.89	0.28	0.09	0.39	4179

LHV: low heat value.

melting furnace running smoothly when LHV of syngas reaches over 4000 kJ/Nm^3. It is suitable when temperature and ER ranged from 550°C to 700°C and from 0.2 to 0.4 respectively in gasifier.

2.2 Analysis of melting experiments

It is reported that when MSW is combusted, there are 72% of Zn, 24% of Cr, 46% of Cd, 30% of Ni, 36% of Cu, 86% of Pb and over 90% of dioxins in fly ash (Sakai and Takatsuki, 2000; Takaoka *et al*., 1997; Li, 2002; Lu, 2004; Hutzinger *et al.*, 1985; Stanmore, 2004). It means that the emphasis should be focused on fly ash to control the emission of dioxins and heavy metals. Melting is considered an environment friendly to dispose fly ash efficiently (Takaoka *et al*., 1997; Wenger and Farouk, 1999).

In this study, three characteristics of fly ash melting were reported, including melting point, decomposition of dioxins, and solidification ratio of heavy metals. The melting point is fulfilled by pyramid method and the results are shown in Fig.5. It indicates that fly ash can be melted when temperature is over 1100°C if residue time is long enough. In order to secure fly ash molten completely and rapidly, temperature of the melting furnace should be over 1200°C in industrial plants.

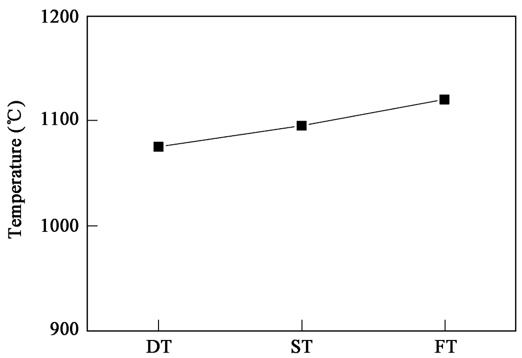

Fig. 5 Melting point of fly ash. DT: deformed temperature; ST: soft temperature; FT: fluid temperature.

Table 5 Contents of dioxins in original fly ash and slag

Materials	Content of dioxins (ng-TEQ/kg)	Decomposition ratio (%)
Original fly ash	275	–
Slag from 1100°C	0.042	99.968
Slag from 1300°C	0.026	99.990
Slag from 1460°C	0	100.000

TEQ: toxicity equivalence quantity.

The experiments of decomposition ratio of dioxins and solidification ratio of heavy metals were carried out at 1100–1460°C in the fixed bed. The contents of dioxins in original fly ash and melted slag were detected by State Key Laboratory of Clean Energy Utilization, Zhejiang University and the results are shown in Table 5. It indicates that more than 99.9% of dioxins were decomposed when temperature was over 1100°C, and when temperature achieved 1460°C, no dioxins can be detected by the instrument (precision: 1 pg/g).

Heavy metals are also pollutants in fly ash. The contents of heavy metals were detected by atomic absorption spectrophotometer and the results are displayed in Table 6. Generally, solidification ratios decreased when temperature ranged from 1100 to 1460°C for volatilization. The solidification ratio of Ni reached over 95% roughly when temperature was 1100–1300°C. The solidification ratio of Cd and Cu fluctuate around 50% when temperature increased from 1100 to 1460°C. Solidification ratios of Cr, Pb and Zn droped sharply when temperature increased from 1300 to 1460°C, which indicates that it is not suitable when temperature is over 1300°C.

2.3 Analysis of principle integrated experiments

On the basis of the results of preliminary studies, a principle integrated experiments were designed and fulfilled using a fluidized-bed gasification and swirl-melting system.

The samples of syngas and flue gas were analyzed, and the results are shown in Table 7.

The results demonstrate that ER of gasification is one of the most important parameters for this system. When ER of gasification decreases from 0.4 to 0.2, temperature of gasification will decrease from 650 to 570°C, and LHV of syngas will decrease from 7200 to 3800 kJ/Nm^3 approximately. When ER of combustion is 1.2, temperature of swirl-melting furnace increases with increasing feeding rate rather than LHV of syngas. The fly ash in flue gas ranges 1.6–1.7 g/Nm^3, which means over 95% ash have been caught by swirl-melting furnace. The percents of SO_2 and NO_x are stable and lower than the criterion of China. Due to the residue time is only 2–3 s in the melting furnace, the percent of CO reaches 200–350 ppmv, which can be resolved voluntarily in industrial plants.

Actually in industrial plant, loss of emission is less 5%. The estimation of thermal balance indicated that MSW of 7000–9000 kJ/kg can be treated by gasification and melting technology, and sieving MSW is a practical scheme for China currently (Xiao *et al*., 2006c).

Table 6 Contents of heavy metals in original fly ash and slag

Item		Ni	Cd	Cr	Cu	Pb	Zn
Original fly ash (mg/kg)		135.1	54.4	271.6	977.1	1300.0	809.0
Slag from 1100°C	Heavy metals (mg/kg)	133.4	24.8	256.6	473.2	803.4	653.7
	Solidification ratio (%)	98.74	45.59	94.48	48.43	61.80	80.80
Slag from 1300°C	Heavy metals (mg/kg)	128.3	26.1	204.5	523.7	564.6	648.9
	Solidification ratio (%)	94.97	47.98	75.29	53.59	43.43	82.68
Slag from 1460°C	Heavy metals (mg/kg)	113.6	27.5	143.4	461.5	365.1	337.5
	Solidification ratio (%)	84.09	50.55	52.79	47.23	28.08	54.80

Table 7 Results of principle integrated experiments

Operating parameter		1#	2#	3#
Fluidized-bed gasification	Feeding rate of MSW (kg/h)	5.4	5.0	7.5
	Flux of air (Nm^3/h)	8	6	6
	ER of gasification	0.4	0.3	0.2
	Temperature of gasification (°C)	647	604	574
	Temperature of preheated air (°C)	308	319	323
	LHV of syngas (kJ/Nm^3)	3884	5469	7222
Swirl-melting furnace	Flux of air (Nm^3/h)	16	18	30
	ER of combustion	1.2	1.2	1.2
	Temperature of melting furnace (°C)	1237	1206	1293
Pollutants in flue gas	Fly ash in flue gas (g/Nm^3)	1.7	1.6	1.7
	Percent of CO in flue gas (ppmv)	346	263	197
	Percent of SO_2 in flue gas (ppmv)	47	53	65
	Percent of NO_x in flue gas (ppmv)	53	76	82

3 Conclusions

In this study, two main preliminary researches and a principle integrated experiment were carried out, and reached the following conclusions.

It is recommended that the temperature of gasifier and melting furnace should be controlled at 500–700°C and at 1200–1300°C respectively. Under these conditions, LHV of syngas reaches about 4000–12000 kJ/Nm^3, the solidification ratios of Ni, Cd, Cr, Cu, Pb and Zn are respectively 95%, 48%, 75%, 54%, 43% and 83% approximately, and decomposition ratio of dioxins achieves over 99.9%.

The principle integrated experiments demonstrate that ER of gasification is one of the most important parameter for this system. The fluidized-bed gasification and swirl-melting system can run smoothly with low emission when ER of gasification and combustion is 0.2–0.4 and about 1.2 respectively. Under these conditions, the temperature of gasifier and melting furnace is 550–650°C and 1200–1300°C respectively, and over 95% of fly ash is caught by swirl-melting furnace.

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