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A Study of Gasification of Municipal Solid Waste Using a Double Inverse Diffusion Flame Burner

Tae-Heon Kwak,[†,‡] Seungmoon Lee,[†] Sanjeev Maken,[†] Ho-Chul Shin,[†] Jin-Won Park,[*,†] and Young Done Yoo[§]

Energy and Environment Lab, Department of Chemical Engineering, Yonsei University, 134 Shinchon-Dong, Seodaemoon-Ku, Seoul, Korea, Woojo Envitech Company, Yeongdeungpo-Gu, Seoul, Korea, and Plant Engineering Centre, Institute of Advanced Engineering, 633-2, Goan-ri, Baegam-myeon,Yongin, Gyeonggi-do, Korea

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Gasification of municipal solid waste was performed with double normal diffusion flame (DNDF) burner (existing technology) and a newly developed double inverse diffusion flame (DIDF) burner, using a process based on Thermoselect. The DIDF and DNDF burners were first optimized for radiation heat flow by changing the ratio of primary oxygen (PO) and secondary oxygen (SO). PO:SO ratios of 3:1 and 1:1 were determined to be the optimum ratios for the DIDF and DNDF burners, respectively. The radiation heat flow for these PO:SO ratios were 56.6 and 36.8 mW for the DIDF and DNDF burners, respectively. The flow rate of slag was also higher (94%) for the DIDF burner than for the DNDF burner (88%). Gasification with the DIDF burner also yields less fly ash and has been determined to be more energy efficient than that with the DNDF burner.

Introduction

Because of industrialization, the quantity of municipal solid waste (MSW) has increased significantly in the developing countries, raising the question of its sustainable disposal management. Waste management systems include waste collection and sorting, followed by one or more of the following options: recovery of secondary materials (i.e., recycling), biological treatment of organic waste (i.e., production of marketable compost), thermal treatment (i.e., incineration to recover energy in the form of heat and electricity), and landfilling.[1−5] The landfilling of MSW releases volatile organic compounds, along with leachable toxic heavy metals and greenhouse gases (GHGs) into the surrounding environment.[6−12] Over the years, incinerating waste to generate energy has become the most common method of dealing with combustible waste efficiently, because it decreases the volume and mass of MSW.[13] However, incineration has drawbacks as well (in particular, hazardous emissions and harmful process residues). The incineration of MSW also generates fly and bottom ashes, which releases leachable toxic heavy metals, dioxin, furans, and volatile organic compounds (VOCs).[14−17] Stringent environmental regulations are being imposed to control the environmental impact of MSW and incinerator residues. Furthermore, the experiences of the waste incineration industry driven in the past by regulatory as well as technical issues may facilitate their commercial potentials outside the common market, especially in highly populated developing countries such as Korea with scarce landfill sites. The total amount of MSW generated by Korea was 48 499 tonnes per day in the year 2001.[18] Approximately 4.6 million tonnes of total waste is being incinerated per year, which leads to the generation of a large amount of solid residues, including

* Author to whom correspondence should be addressed. Telephone: +82-2-364-1807. Fax: +82-2-312-6401. E-mail address: jwpark@yonsei.ac.kr.
† Yonsei University.
‡ Woojo Envitech Company.
§ Plant Engineering Centre, Institute of Advanced Engineering.

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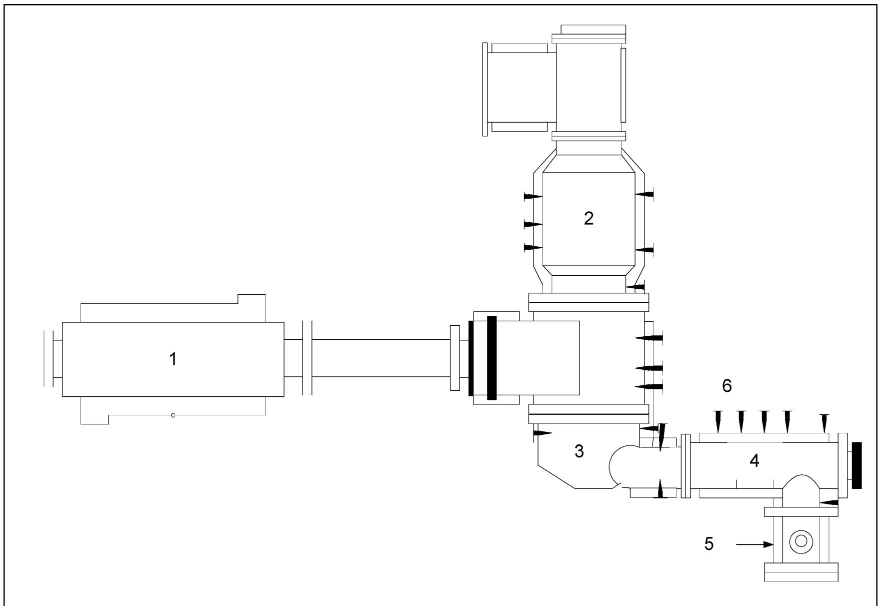

1. Degassing Facility	4. Homogenization Reactor
2. High Temperature Reactor	5. Granule Cooling Tank
3. High Temperature Reactor Bottom	6. Double Inverse Diffusion Flame Burner

Figure 1. Schematic diagram of the gasification/melting process.

fly ash and bottom ash,[19,20] and also emit hazardous gases into the environment.

Moreover, thermal waste disposal can no longer be considered as a process for the reduction of the amount of MSW by weight and volume with the disposal of the generated ashes and air pollution control residues on landfill sites or their application in cement and construction industry. Thus, there is a need to consider MSW as a valuable indigenous source of fuel that is abundant especially in consumer-oriented societies that are able to substitute fossil fuels in power generation and other industrial processes. Increasing space constraints for the landfilling of MSW and public opposition to new incinerators for waste disposal has effectively eliminated this as a future option in many countries.

Recently, several new technologies that involve gasification or combinations of pyrolysis, combustion, and gasification processes are currently being brought into the market for energy-efficient, environmentally friendly and economically sound methods of thermal processing of wastes.[21,22]

Recently, Daewoo Engineering & Construction Corporation installed high-temperature recycling pilot plants for waste of any type with a patented process called Thermoselect with the collaboration of THERMOSELECT, Switzerland. The process consists of compression, degassing with fixed-bed oxygen-blown gasification, and melting of mineral residues.[23] The purpose of this study is to optimize the gasification of MSW in a pilot plant using a newly designed double inverse diffusion flame (DIDF) burner[23] and compare it to the existing double normal diffusion flame (DNDF) burner.

Experimental Methods

MSW collected from S-city in Korea was used for gasification in a 3-ton/day-capacity pilot plant. The process is based on the Themoselect process and is shown schematically in Figure 1. The gasification was performed with DIDF and DNDF burners using liquified petroleum gas (LPG) as a fuel. A comparison between the two burners is given in Table 1. The operating conditions of the gasification with each type of burner are shown in Table 2.

In the pilot plant, pyrolysis and gasification processes were performed in a single unit.[24−27] The unsorted MSW was compacted to approximately one-fifth of their original volume by means of a hydraulic press and then pushed into an indirectly heated long canal that was maintained at temperatures higher than 600 °C. The compression enabled the canal to be airtight. As waste plugs moved through the canal, they get heated, dried, and almost completely pyrolyzed when they reached the end of the canal. The pyrolysis products were then entered into the gasification zone, where the materials were gasified with oxygen at a temperature of ∼1200 °C. A high-quality synthesis gas and a molten slag were formed. The gas was rapidly cooled from 1200 °C to 90 °C, to avoid the

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Table 1. Comparison between the Double Inverse Diffusion Flame (DIDF) Burner and the Double Normal Diffusion Flame (DNDF) Burner

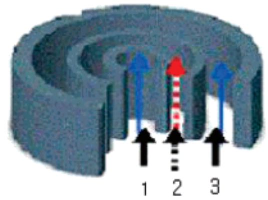
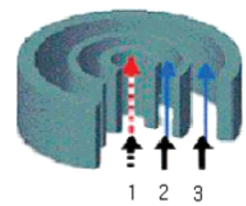
	DIDF	DNDF
principle	melting of MSW by heat radiation, using a double inverse diffusion flame burner	melting of MSW by heat radiation, using a double normal diffusion flame burner
features		
core of burner	primary oxygen (PO) input (75%)	fuel input
external of burner	fuel input	primary oxygen (PO) input (50%)
peripheral of burner	secondary oxygen (SO) input (25%)	secondary oxygen (SO) input (50%)
heat radiation	56.6 mW	34.8 mW
configuration of burner	 1. primary oxygen (PO) input (75%) 2. fuel input 3. secondary oxygen (SO) input (25%)	 1. fuel input 2. primary oxygen (PO) input (50%) 3. secondary oxygen (SO) input (50%)

Table 2. Operating Conditions for Gasification of MSW Using Double Inverse Diffusion Flame (DIDF) Burner and Double Normal Diffusion Flame (DNDF) Burner

burner	MSW input (kg/h)	LPG (L/min)	oxygen flow rate (Nm^3/h)	furnace pressure (kg/cm^2)	HTR temp (°C)	homogenized furnace temp (°C)	HTR outlet temp (°C)
DIDF	128.7	195	103	0.05−0.2	1290−1380	1400−1480	>1200
DNDF	142.5	238	82	0.01−0.03	1270−1330	1330−1450	>1200

re-formation of dioxin and furans, and thereafter cleaned and made available for power production. The molten byproduct flows into the combustion zone, where, with a supply of oxygen and fuel, combustion occurs at a temperature in excess of 1600 °C, ensuring the thermal destruction of all chlorinated carbon and stabilization of heavy metals.

The composition of the MSW was studied by proximate and ultimate analysis, and melted slag was dried at a temperature of 110 °C for 24 h. After drying, these were pulverized to a size of <300 μm and were screened through a size of 300 μm. Chemical compositions of slag were analyzed using X-ray fluorescence (XRF).

Results and Discussion

The composition of MSW was analyzed by proximate and ultimate analyses, and the results are shown in Table 3, along with its lower heating value (LHV). The gasification of MSW was conducted with two types of burners: a DNDF burner (existing technology) and a DIDF burner (which was developed by the Institute of Daewoo Corporation; depicted in Figure 2 of ref 23). The DIDF and DNDF burners were first optimized to determine the maximum radiation heat flow, using different primary oxygen (PO) to secondary oxygen (SO) ratios. The radiation heat flow for DIDF was determined to be maximum (56.6 mW) at PO:SO = 3:1, and, for DNDF, it was maximum (34.8 mW) for PO:SO = 1:1. The radiation heat flow versus flame height plots for the DNDF and DIDF burners are shown in Figures 2 and 3, respectively. This shows that the DIDF burner had better radiation heat flow than the DNDF burner.

Next, we correlated the high heating value (HHV) of MSW with the amount of oxygen and amount of fuel required for gasification and total energy input (the sum of the heating value of the fuel and the HHV of MSW). In this experiment, four MSW samples (S-1, S-3, S-4, S-5), with different HHVs, were gasified using the DNDF burner (S-1) and the DIDF burner (S-3, S-4, S-5). For every sample of MSW, a batch of ∼4−5 kg of waste

Table 3. Composition of MSW (Sample S-2) and Chemical Composition of Slag

classification	value
proximate analysis	
moisture	40.25 wt %
volatile matter	45.95 wt %
fixed carbon	5.43 wt %
ash	8.37 wt %
ultimate analysis	
C	49.7 wt %, db
H	6.5 wt %, db
O	36.0 wt %, db
N	0.12 wt %, db
S	0.21 wt %, db
ash	6.49 wt %, db
total	100 wt %, db
component of slag	
Al_2O_3	17.42 wt %
SiO_2	36.18 wt %
Fe_2O_3	14.28 wt %
TiO_2	0.85 wt %
CaO	9.63 wt %
MgO	3.53 wt %
K_2O	0.61 wt %
Na_2O	1.20 wt %
P_2O_5	2.27 wt %

was fed into the compression unit at the regular interval of time so that total waste feed rate was 120 kg/h. Data (the amount of oxygen, fuel, and total energy input) were collected after every 10 min. The average of these values after each hour were plotted against the HHV of MSW in Figure 4. For each HHV MSW sample, at least five average values were plotted in Figure 4. A total of four HHV MSW samples were studied in this gasification experiment. Figure 4 clearly shows that the total input energy required for gasification is maximum for the case of the DNDF burner (S-1), as compared to the DIDF burner (S-3, S-4, S-5). For the case of the DIDF burner, among three MSW samples (S-3, S-4, S-5), the MSW sample with an HHV of 14.65 MJ/kg (S-5) required the optimum amount of fuel and oxygen for the gasification. Therefore, MSW with an HHV of 14.65

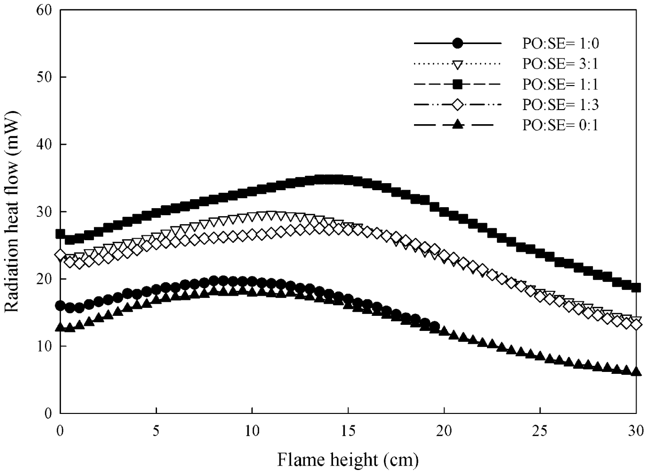


Figure 2. Radiation heat flow with flame height using a double normal diffusion flame (DNDF) burner with different primary oxygen (PO) to secondary oxygen (SO) ratios.

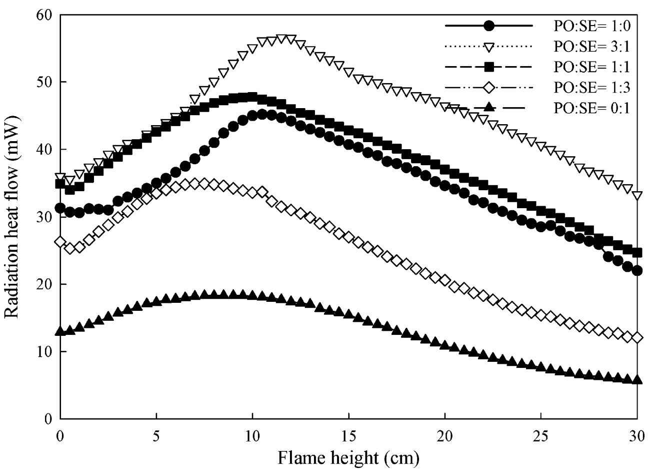


Figure 3. Radiation heat flow with flame height using a double inverse diffusion flame (DIDF) burner with different primary oxygen (PO) to secondary oxygen (SO) ratios.

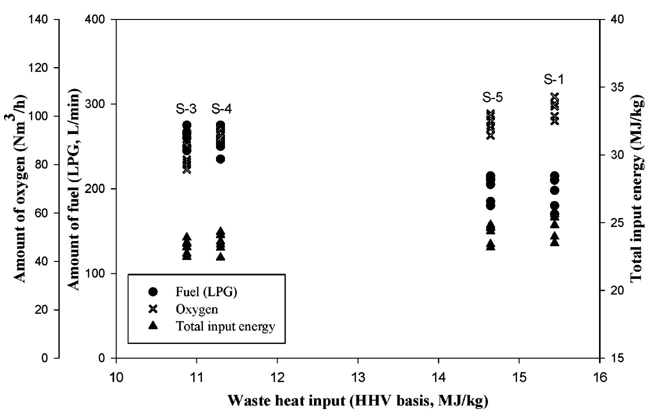


Figure 4. Correlation of high heating value (HHV) of MSW with the amount of oxygen, fuel, and total input energy (HHV of MSW + heating value of fuel) during gasification with a DNDF burner (S-1) and a DIDF burner (S-3, S-4, S-5) (MSW amount = 120 kg/h).

MJ/kg was selected for the next experiment, to study the correlation of the amount of MSW gasified with the amount of oxygen and fuel required for gasification and total energy input (the heating value of the fuel and MSW). This experiment was performed in a manner similar to that of the previous experiment with MSW

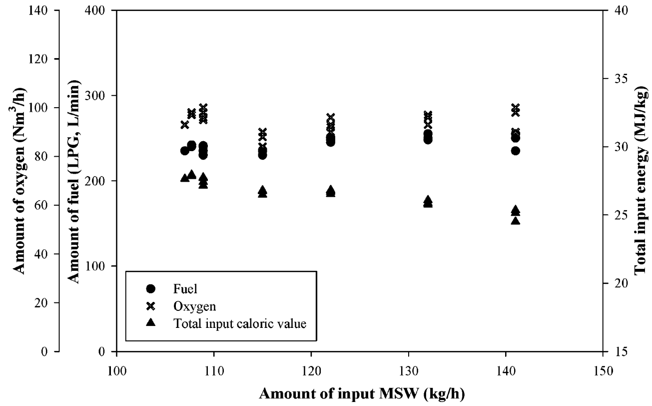


Figure 5. Correlation of the amount of MSW with the amount of oxygen, fuel, and total input energy (HHV of MSW + heating value of fuel) during gasification with a DIDF burner (HHV of MSW = 14.65 MJ/kg; sample S-5).

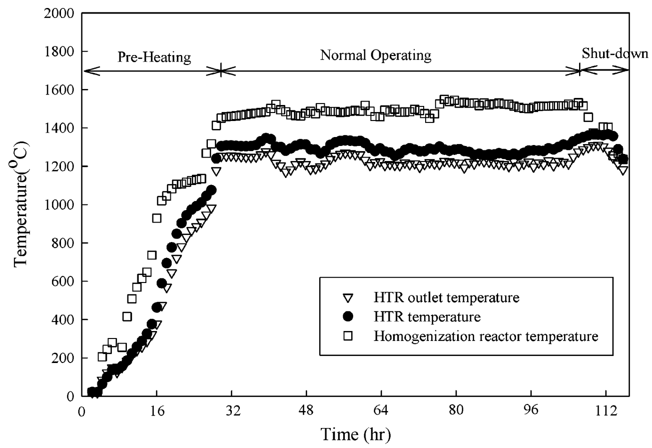


Figure 6. Variation of temperature of reactor with the progress of gasification of MSW using a DIDF burner (MSW sample S-5).

that had a fixed HHV (14.65 MJ/kg) but with six different amounts of MSW. The amount of MSW gasified in this experiment was varied from 107.8 kg to 142.5 kg. Correlation of the amount of MSW gasified with the amount of oxygen, fuel, and total energy input values were shown in Figure 5. Figure 5 shows that an MSW input of 142.5 kg/h seems to be the optimum amount, because it consumed the minimum amount of fuel as well as a minimal amount of total input energy and oxygen.

During the continuous processes of gasification (preheating, normal heating, and shutdown), the temperature was recorded at three different points: at the high-temperature reactor (HTR), at the homogenization reactor, and at the outlet of the HTR (the temperature at these three points, relative to time, are plotted in Figure 6). The molten, not gasifiable, waste components slowly flow into the homogenization reactor that is directly connected to the HTR, where temperature is maintained above the solidification temperature of the melt (at ~1550 °C). The flow rate of slag was also determined to be higher for the DIDF burner (94%) than for the diffusion burner (88%) (see Table 4). This further shows the better melting of slag with the DIDF burner. Moreover, gasification with the DIDF burner yields less fly ash (0.76 kg/h, 0.59% of MSW) than that with the DNDF burner (1.36 kg/h, 0.95% of MSW). The vitrified

Table 4. Flow Rate of Slag, Fly Ash, and Weight Loss during for Gasification of MSW, Using a Double Inverse Diffusion Flame (DIDF) Burner and a Double Normal Diffusion Flame (DNDF) Burner

			residues (kg/h)			weight loss (%)	
burner	MSW sample	waste through input (kg/h)	slag	fly ash	slag recovery rate (%)	slag + fly ash	fly ash
DIDF	S-2	128.7	11.97	0.76	94	90.13	99.41
DNDF	S-1	142.5	9.97	1.36	88	92.05	99.05

Table 5. Low and High Heating Values of MSW along with Composition of Synthesis Gas

				composition of synthesis gas (vol %, dvb[a])				
burner	MSW sample	low heating value, LHV (MJ/kg)	high heating value, HHV (MJ/kg)	CO	H_2	CO_2	O_2	CH_4
DNDF	S-1	13.82	15.45	32.05	28.94	27.21	0	1.68
DIDF	S-2	13.82	15.45	29.59	30.73	26.86	0	0.08
DIDF	S-3	9.31	10.88	34.23	37.54	27.43	0	0
DIDF	S-4	9.88	11.30	24.80	32.70	23.30	0	0.9
DIDF	S-5	13.42	14.65	31.41	27.66	28.60	0.07	2.23

[a] Dry volume basis.

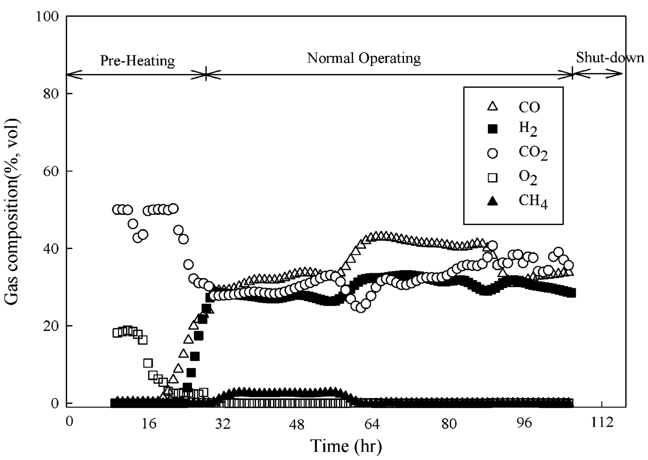


Figure 7. Variation in synthesis gas composition with the time of gasification of MSW, using a DIDF burner (MSW sample S-5).

mineral aggregate possesses the quality of natural raw materials and could be used as construction material.[28]

Figure 7 shows the composition of the synthesis gas during preheating and under normal operating conditions. The compositions of the synthesis gas were obtained over a regular time interval (1 h) and differ only slightly from each other. This might be due to the varying MSW compositions. During the preheating phase, it contains less H_2 and CO, but these quantitites increased under normal operating conditions. Note that only a very small quantity of methane was found in the synthesis gas with no oxygen (see Table 5). This further proves the effectiveness of the gasification using the DIDF burner.

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Conclusion

The gasification of municipal solid waste (MSW) was studied using the newly designed double inverse diffusion flame (DIDF) burner and the double normal diffusion flame (DNDF) burner (existing technology) using a process that is based on Thermoselect. Gasification with the DIDF burner was determined to be better than that with the DNDF burner in the following ways:

(1) The radiation heat of the DIDF burner (56.6 mW) was ∼63% greater than that observed for the DNDF burner (34.8 mW).

(20 The slag recovery rate was higher in the DIDF burner (94%) than in the DNDF burner (88%).

(3) The generation of fly ash was less in the DIDF burner (0.76 kg/h, 0.59%) than in the DNDF burner (1.36 kg/h, 0.95%).

(3) Gasification with the DIDF burner was more energy efficient than that with the DNDF burner, because it consumed less energy during the gasification, with the production of a better-quality synthesis gas.

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