Preliminary Study of the Pyrolysis of Steam Classified Municipal Solid Waste

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ABSTRACT

Steam classified municipal solid waste (MSW) has been studied for use as a combustion fuel, feedstock for composting, and cellulytic enzyme hydrolysis. A preliminary study has been conducted using a prototype plasma arc pyrolysis system (in cooperation with Plasma Energy Applied Technology Inc., Huntsville, AL) to convert the steam classified MSW into a pyrolysis gas and vitrified material. Using a feed rate of 50 lbs/h, 300 lbs of the material was pyrolysized. The major components of this pyrolysis gas were H_2, CO, and CO_2. A detailed presentation of the emission data along with details on the system used will be presented.

Index Entries: Municipal solid waste; gasification; pyrolysis; biomass; plasma arc.

INTRODUCTION

In 1990, the United States generated an estimated 195 million tons of municipal solid waste (MSW) (1). The primary method used for disposal of MSW is landfilling. About 75% of existing landfills are expected to close in the next 10 to 15 y. New environmental laws have made landfilling much more expensive (2). Incineration, another method of MSW disposal, is often more expensive than landfilling and is not very popular with the public because of the pollution concerns.

A method called "Steam Classification" has been developed at the University of Alabama in Huntsville (UAH) to treat MSW (3,4). With the addition of moisture, the waste is exposed to saturated steam under pressure for approx 1 h with constant mixing. The biomass components are predominantly transformed into a reasonably uniform material that can be isolated from most of the glass, metals, textiles, and plastic through the use

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of a trommel and air classifier. This material has been studied in conjunction with composting, enzyme hydrolysis, and incineration *(5,6)*. Steam classification has been found to produce a better product than conventional methods of refuse-derived fuel (RDF) preparation.

The purpose of this study is to examine the gasification of steam classified MSW. This was achieved using a plasma arc pyrolysis unit at Plasma Energy Applied Technology (PEAT), in Huntsville, Alabama, that was originally developed for disposal of hazardous waste. High temperatures under controlled process conditions to promote physical and chemical changes in material are used. The waste is converted to a pyrolytic gas and a vitrified solid. A plasma arc pyrolysis system was used because it was the only gasification system available at the time. Because of the preliminary nature of this study, a cost analysis has yet to be done.

METHODS

Steam Classification

Steam classification is a method whereby essentially unsorted MSW can be processed and subsequently separated into biomass and nonbiomass fractions. A combination of continuous mixing with added moisture as well as pressurized with saturated steam basically pulps or repulps cellulosic materials to a relatively uniform material by size and density. After processing, this biomass material can be separated from nonbiomass components for use as a chemical feedstock. The nonbiomass components can be separated into recyclable metals, glass, textiles, and plastics with only a minor fraction requiring disposal *(4)*.

The steam classified material used for this study was produced in Walton, KY. Approximately seven metric tons of ordinary municipal solid waste was placed inside a vessel along with some water. The vessel was thereupon closed and pressurized to about 400 kPa with saturated steam (150°C). The vessel was rotated, thus mixing the waste with internal helical flighting, for about 1 h. The vessel was depressurized and the contents were emptied onto a conveyor that transferred the material to a rotary trommel. The trommel separated out the material that was less than 3 cm from larger components. Recyclable materials were manually sorted before the remainder was landfilled. A composite sample of about 5000 kg of the under 3 cm material was transported to UAH. The material was then screened on a vibratory screener to recover the <1.3-cm fraction. This fraction was then air classified to remove most of the glass and remaining dense contaminants.

Plasma Arc Pyrolysis

Plasma, the fourth state of matter, is the universe's most common form of matter. It is basically an energetically charged gas. Fundamentally, the plasma arc torch consists of an electrically neutral gas forced through
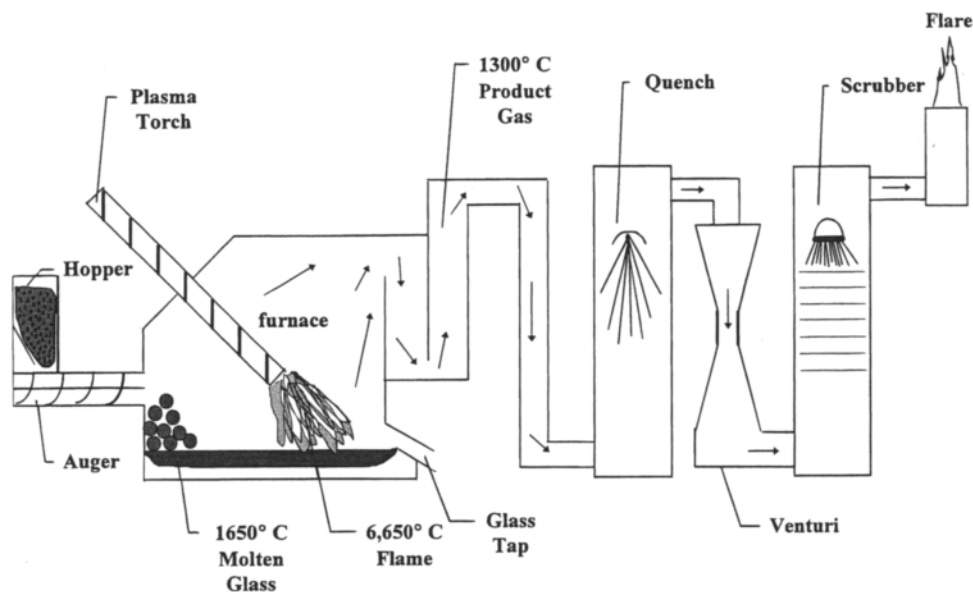
Fig. 1. Schematic representation of the Plasma Energy Applied Technology, plasma arc pyrolysis pilot plant.

the electric arc created between two electrodes in a metallic tube. It is possible to split complex materials into their basic compounds and individual elements because the torch reaches temperatures in excess of 6650°C heating the pyrolysis vessel to over 1650°C. Oxygen is restricted to the minimum necessary to accomplish gasification by utilizing steam as the oxidant, thus the gaseous atmosphere remains very reducing and has an abundance of hydrogen. The volume of off-gas is also reduced significantly compared to combustion, thus minimizing any cleanup of the gas *(7)*.

The final biomass material prepared at UAH was transported to the PEAT facilities for the pyrolysis test. Batches of the material were loaded into a feed hopper and continuously fed via an auger into the pyrolysis unit. The feed rate had to be varied somewhat from 19 to 23 kg/h in order to prevent a buildup of unreacted material inside the unit. Early in the test a buildup of a white powder was observed that was determined to be kaolin from the paper products in the feed material. To eliminate the powder, soda ash (Na_2CO_3) was added with each batch of feed material.

For our test, the unit was heated to between 1260°C and 1315°C. Figure 1 shows a schematic of the PEAT pyrolysis process system.

The steam classified MSW was added to the hopper in measured batches. As the lid was closed the hopper is pressurized with N_2 driving air out and keeping a positive pressure. The feed screw fed the material into the furnace at a measured rate. As the material is consumed it is trans-
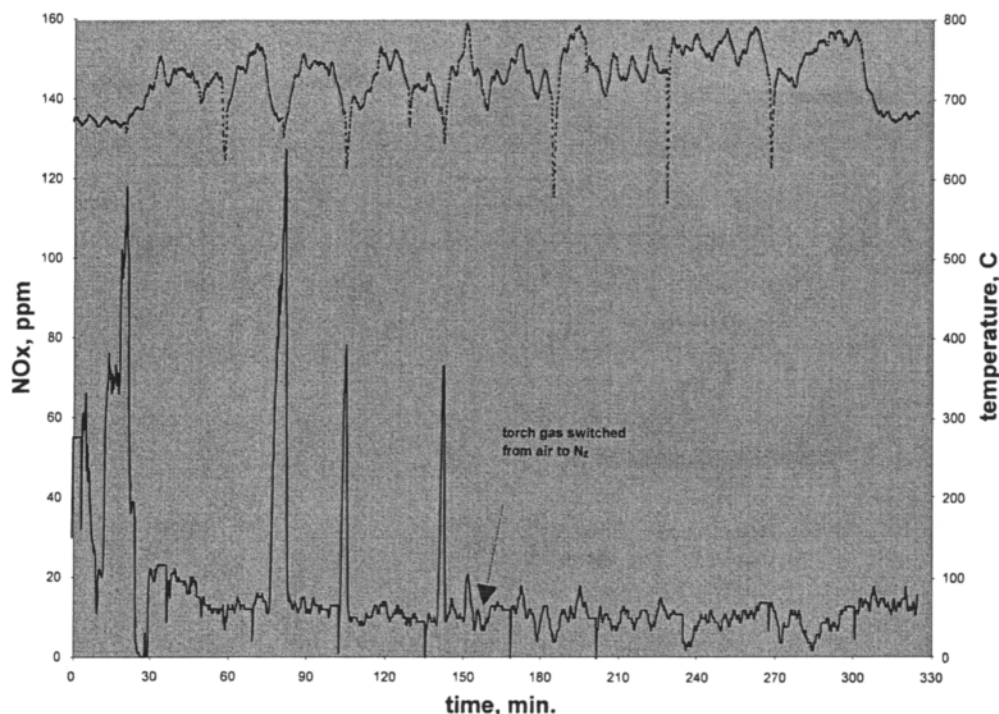
Fig. 2. Greenline Combustion Gas Analyzer data for NO_x and temperature mea-
sured after the flare. Note the change from air to N_2 as the torch gas at 160 min into the
test. —— NO_x, ppm; - - - - flare temp., °C.

formed to either a gas or a vitrified slag. The slag is periodically tapped. The
acid gases were measured at the rear of the pyrolysis unit as the gases exited
the furnace. After exiting the furnace, the gases entered the quench that con-
sists of a spray mist of city water at tap temperature that cooled the gases.
The cooled gases pass into a venturi that includes an alkaline spray mist to
extract most of the particulates and partially neutralize the acid gases. A
scrubber was then used to scrub any remaining acid gases from the off-gas.
A sodium hydroxide (NaOH) solution was used in both the venturi and
scrubber. Particulates from the water quench, the venturi, and the scrubber
are combined, recovered in a filter press, and reprocessed in the furnace.
After exiting the scrubber, the product gas was saturated with water. The
gas concentration was monitored at this point. The CO and CO_2 were mea-
sured using a Teledyne Model 731 nondispersal infrared analyzer. A Model
235 thermal conductivity analyzer monitored H_2. The CH_4 infrared sensor
did not work in our test. The product gas entered a flare fueled by propane
and air, and was combusted before being exhausted to the atmosphere.
Before leaving the stack a number of measurements were taken. Using a
Eurotron "Greenline" Combustion Gas Analyzer, the O_2, CO, CO_2, NO,
NO_x, and SO_2 were measured. The SO_2 analyzer did not work for this test.
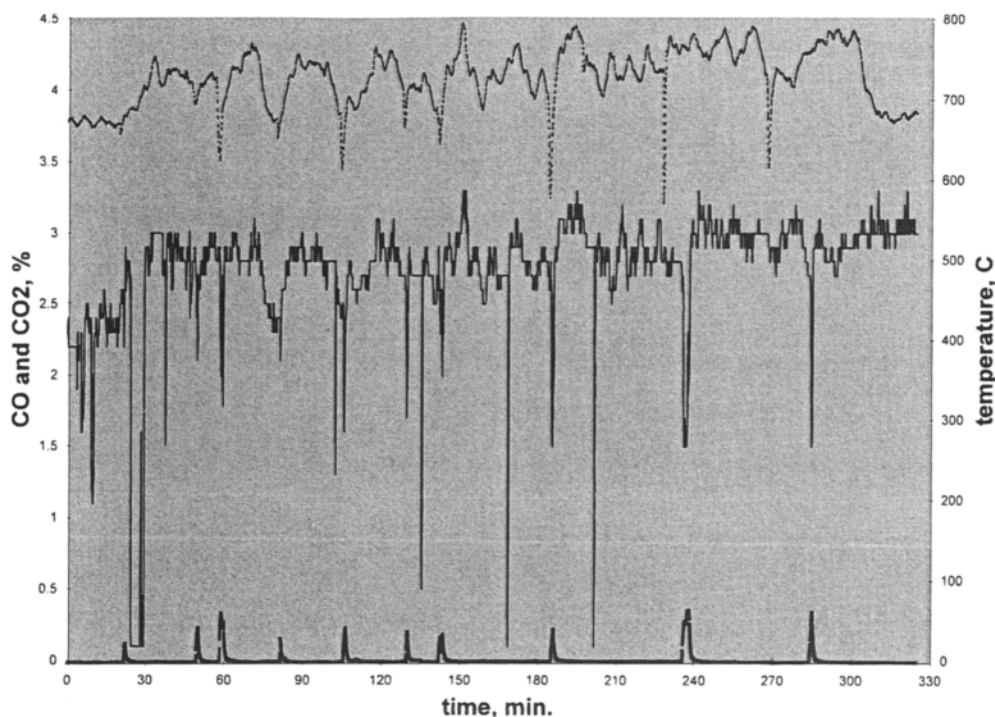Also measured were the metals, dioxins/furans, and particulates.

Fig. 3. Greenline Combustion Gas Analyzer data for CO and CO_2, after the flare and the flare temperature. Note that the CO_2 levels at this location would also include the combustion of propane. — —, CO, %; ——, CO_2, %; - - - -, flare temp., °C.

RESULTS AND DISCUSSION

Feedstock material was fed into the pyrolysis furnace over a period of 5 h 10 min, except for an occasional interruption to prevent accumulation of unreacted material in the furnace chamber. In the first 10 min a white powdery material was noted to accumulate in the furnace. It was determined to be kaolin, which is an additive of paper products. Soda ash (Na_2CO_3) was added as a flux agent to reduce or eliminate the kaolin floc.

The Greenline gas analyzer continuously monitored the gases at the flare exhaust. Since air was admitted at the base of the flare, the oxygen was in excess to allow the complete combustion of the propane and product gas before release to the atmosphere. During the first 2 ½ h it was noted that the NO and NO_x levels fluctuated excessively. The whole time the torch gas had been compressed air. It should be noted the quantity of air was insufficient to support combustion. It was then decided to switch the torch gas to compressed nitrogen, which considerably dampened the fluctuations in the NO/NO_x regions (see Fig. 2). The difference in the NO and NO_x readings were not significant. The flare temperature, plotted in Fig. 2, with only a few exceptions was maintained above 700°C. Except for a few spikes
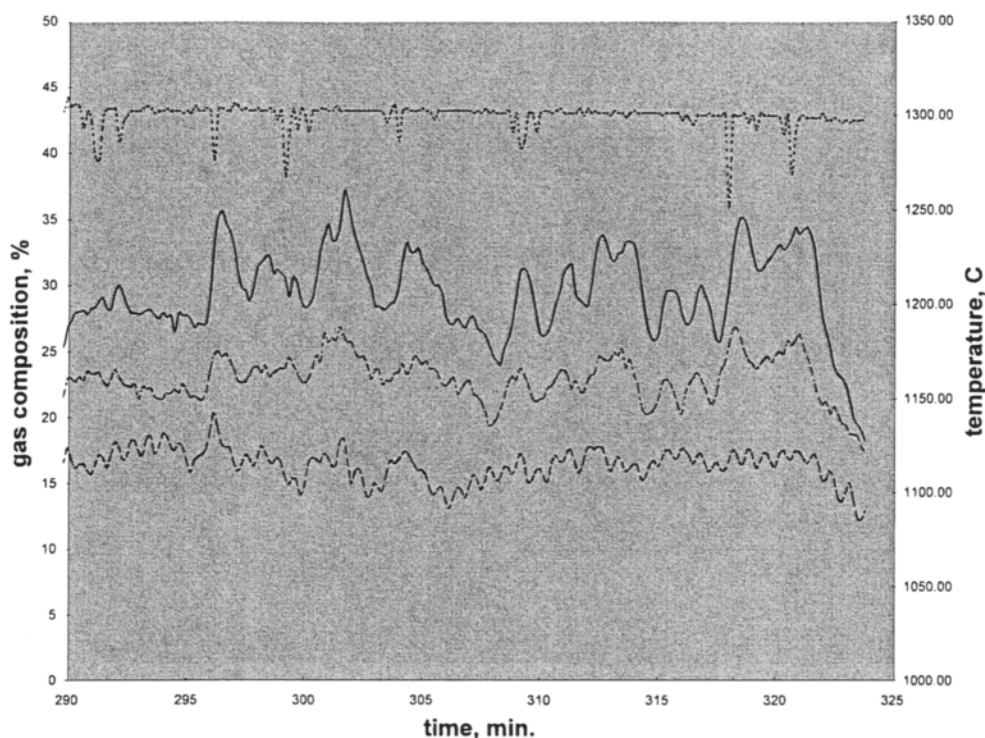
Fig. 4. Teledyne Model 731 Nondispersal Infrared Analyzer data for CO and CO_2 and Model 235 Thermal Conductivity Analyzer data for H_2 measured at the furnace exit. Furnace gas temperature is also included. Note that this data was collected only during the last 30 min of the test because of a gas sampling line blockage. ———, H_2; — - - —, CO; — — —, CO_2; - - - -, furn. gas temp., °C.

Table 1
Ultimate Analysis

Parameter	Dry Basis	As Received
% Moisture	0	50.54
% Carbon	39.79	19.68
% Hydrogen	5.47	2.71
% Nitrogen	0.83	0.41
% Sulfur	2.18	1.08
% Chlorine	0.77	0.38
% Ash	17.16	8.49
% Oxygen	33.8	16.72
fuel value (kJ/kg)	18,530	9,160

before the torch gas was changed from air to N_2, the NO_x level did not exceed the EPA limit of 180 ppm when corrected to 7% oxygen (8,9).

Although the CO concentration of the product gas was a major constituent of the product gas prior to combustion in the flare, the postflare CO

Table 2
Product Gas Composition and Temperatures

	H_2	CO	CO_2	Gas Temp., °C	Furn. Gas Temp., °C
average	29.49	22.97	16.39	34.56	1299.43
standard dev	3.23	1.69	1.26	0.40	6.48

Table 3
Acid Gas Analyses

Gas	measurements
	ppb
H_2S	104
Sulphate	9.042
Nitrate	0.319
Fluoride	0.28
Chloride*	0.205
Nitride	0.015
* EPA Limit - 35 ppm	

levels were reduced to almost zero. It should be noted that air is being admitted in excess at the base of the flare stack, thus promoting combustion. A few spikes of less than a half percent were noted shortly after each feed interruptions. The same figure also shows concentrations of CO_2 mostly in the range of 2.5–3%, resulting from the combustion of the product gas and propane in the flare (*see* Fig. 3).

Figure 4 shows the composition of the product gas prior to combustion in the flare only during the last half hour of the run. Previous to this time, inadequate readings indicated a low gas yield that was inconsistent with the quantity of feed material having a composition as noted in Table 1. Although a number of troubleshooting measures were taken during the entire run to identify the problem, it was not until the last half hour that the problem was identified and corrected. The gas sampling line to the Teledyne analyzer was partially blocked, and this blockage was removed by forcing air through the line. Table 2 shows the average composition and standard deviations after the correction. The significant quantities of H_2 and CO present indicated a combustible gas. The unaccounted portion of the gas was predominantly moisture since the gas was saturated during clean-up. The temperature of the product gas as it leaves the furnace is also indicated in the figure with the average also found in Table 2.

The exhaust gas from the furnace was sampled prior to the water quench for acid gas components. Table 3 shows the results of these analyses. Although in ppb the only acid gases of note were those containing sulfur, which probably results from the relatively high (approx 2% dry

Table 4
Metal Analysis

Metals	Analysis ppm	EPA Limit ppm
Copper	0.09	
Lead	0.73	5.0
Chromium	<0.02	5.0
Selenium	<0.2	1.0
Arsenic	<0.08	5.0
Mercury	0.14	0.2
Barium	<0.01	100.0
Silver	<0.01	5.0
Nickel	<0.05	
Potassium	<0.83	
Sodium	2.22	
Manganese	<0.01	
Cobalt	<0.07	
Zinc	0.19	
Iron	<0.07	
Cadmium	0.02	1.0
Magnesium	0.05	
Aluminum	0.08	
Calcium	0.45	
Beryllium	<0.01	

Table 5
Particulates*

Location	emissions ppb
Post Quench	25871
Post Quench	12504
Post Quench	37339
Post Flare	55.4
Post Flare	177.2
Post Flare	83.0
* EPA Limit - 34 ppb	

weight) of sulfur noted in the ultimate analysis (Table 1). The HCl level measured, 0.21 ppb, did not approach the EPA limit of 35 ppm *(8)*. Table 4 shows the results from a metals analysis collected after combustion of the product gas. The only metal found in significant quantity was sodium,

Table 6
Dioxins and Furans*

Analytes	Sample 1 ng/m^3	Sample 2 ng/m^3
1234678-HpCDD	{0.02}	0.03
OCDD	0.16	{0.14}
1234678-HpCDF	0.03	{0.03}
OCDF	{0.06}	0.36
TOTAL HpCDD	{0.04}	0.05
TOTAL TCDF	{0.01}	
TOTAL HpCDF	0.04	0.01
{Est. Maximum Possible Concentration}		
* EPA Limit - 30 ng/m^3		

which is indicative of added soda ash. It should be noted that all EPA-regulated metals are below acceptable emission levels.

Table 5 shows the particulate levels before and after the venturi and gas scrubbing treatment, which indicates a significant reduction in the quantities of particulates by such treatment. The postflare levels are approx 2–5 times the allowable EPA emission level of 34 ppb *(8)*, thus indicating additional gas cleaning would be necessary, such as a larger scrubber or a baghouse. The particulates were measured in accordance with EPA Method 5, Appendix A. The size and solubility were not measured. Semivolatiles, including dioxins and furans, were also collected after combustion. Table 6 shows that the dioxins and furans are well below the EPA limit of 30 ng/m^3 *(8)*. Other semivolatiles detected at levels of parts-per-trillion were Phenol, Benzoic acid, Di-n-butylphthalate, and bis(2-Ethylhexyl)phthalate.

ACKNOWLEDGMENTS

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