Theoretical and Engineering Research on the Municipal Solid Waste Plasma Gasification

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ABSTRACT

Plasma gasification is an advanced and environmentally friendly technology for the disposal of municipal solid waste (MSW) with energy recovery. Based on the requirement for the treatment of MSW in Beijing, the conceptual design for a 50 t/d demo plasma gasification system for preprocessed MSW has been done. The raw MSW is preprocessed by a pretreatment system, where the raw MSW is heated up to 180°C under 0.7 MPa by steam, and then released rapidly into the vessel under atmospheric pressure. After pre-processing, kitchen garbage and dust can be easily screened out from raw MSW. The moisture of sorted MSW can be reduced to 30% and a lower heating value (LHV) of the pre-processed MSW can reach 13 000 kJ/kg. The pre-processed MSW is gasified in the plasma reactor, where the plasma torches of 600 kW in total are used, in order to produce the syngas to feed a gas engine generator of 2.5MW. 30% of stoichiometrical air was fed into the reactor to get better syngas. The reaction temperature is kept at 1000°C for 5 seconds in the reactor chamber, where the dioxins can be fully destroyed. The syngas is cleaned before it is feed in to the engine. A special syngas-water heat exchanger is designed to recover energy of the hot syngas and to avoid corrosion of HCl gas under high temperature and of hydrochloric acid below the dew point. Meanwhile, dioxins formation is prevented,

since the cooling process duration of syngas is shorter than 0.5 second under 200°C to 500°C.

INTRODUCTION

In the field of environmental protection, thermal plasma technology has been used for the pyrolysis of hazardous waste, such as persistent organic pollutants (POPs) [1], and ozone depleting substances [2]. Recently, more and more scientists start to use this technology for assisting the gasification of municipal solid waste (MSW) [3], medical waste [4], and biomass [5, 6].

Compared with pyrolysis technology under neutral or reductive atmosphere, more energy can be recycled from wastes by gasification technology under partial oxidizing condition, which means the economic benefits will be remarkably increased. A small part of the chemical energy (less than 15%) stored in the organics will be released during the gasification process, and the organics are decomposed and reformed into syngas through the partial oxidizing reaction simultaneously, then the cleaned syngas that contains the rest of the chemical energy of the wastes could be used as chemical industry materials or used to generate electrical power.

Plasma gasification technology is not the only way to assist or enhance the gasification processing of organic waste, but it indeed has some unique advantages. For example, the temperature of the thermal plasma is very high, more than 6 000°C, and there are large amount of reactive ions, electrons, and free radicals in the plasma, which means it has very active chemical activities that can accelerate the reaction process. With the extra energy added by thermal plasma, the gasification temperature can be kept at 1000°C, so the dioxins can be destroyed in the reactor and the reformation of the dioxins will be prevented in the cooling process, which is very important in the thermal treatment of the MSW or other chlorinated wastes.

More than 18 000 tons per day of MSW will be generated in Beijing. How to treat the huge amounts of MSW safely now becomes a severe problem for the government. During the last decades, landfill treatment has occupied a lot of precious land in

Beijing. Meanwhile, with the gradual awakening of public environmental awareness, building incineration facilities to replace landfill is also facing strong resistance. As a technology alternative to incineration, plasma gasification technology has been chosen by the Beijing government as a promising way to treat the MSW.

The conceptual design for a plasma gasification demonstration (demo) plant for 50 t/d preprocessed MSW from 200 t/d raw MSW, has been made by the Institute of Mechanics, Chinese Academy of Sciences (IMECH/CAS). More details are further discussed in this paper.

MSW PLASMA GASIFICATION FACILITY

Overview

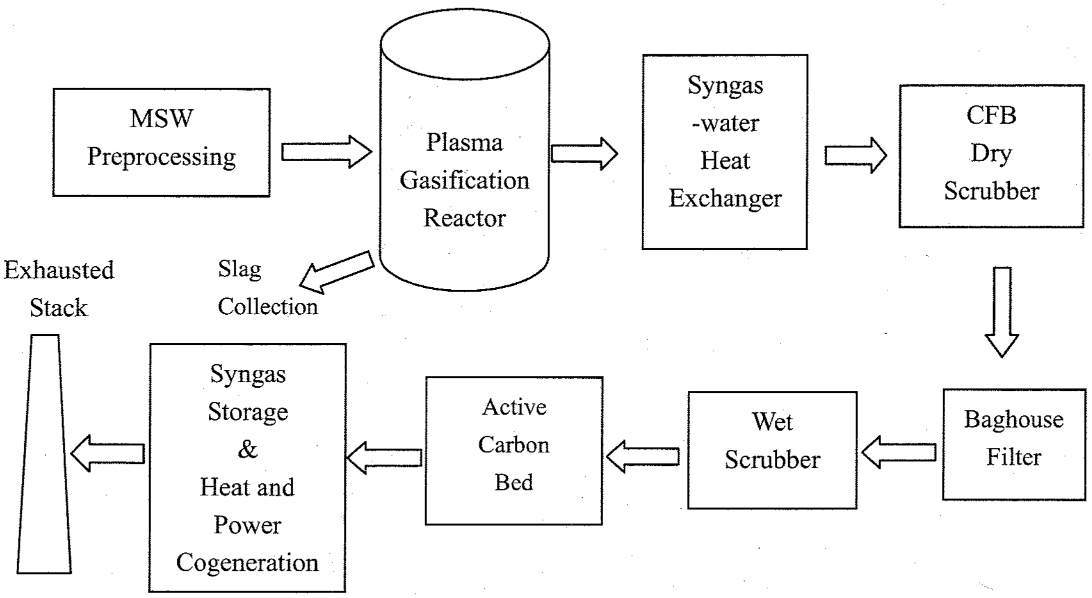
Through the implementation of several plasma pyrolysis and vitrification pilot projects in China for chemical byproducts and POPs, IMECH, CAS has accumulated abundant knowledge and experience in thermal plasma treatment of wastes. Combining experience from the designing MSW incineration facilities and the plasma gasification facilities independently have lead to some important innovations.

Figure 1 shows the process flow chart of the MSW plasma gasification facility. As shown, the system consists mainly of a MSW preprocessing system, a plasma gasification reactor, a slag collection system, a syngas-water heat exchanger, a circulating fluidized bed (CFB) dry scrubber, a bag house filter, a wet scrubber, an active carbon absorption equipment, a syngas storage system, a heat and power cogeneration system, and an exhausted stack. Detailed design characteristics for each system part are described in following sections.

Preprocessing System

Since raw MSW in Beijing is very wet and mixed with lots of food residues and non-combustibles, a preprocessing system was designed to improve the energy efficiency. The raw MSW is preprocessed by a pre-treatment system, where raw MSW is heated to 180°C under 0.7 MPa by steam, and then released rapidly into a vessel under atmospheric pressure. After pre-processing, kitchen garbage and dust in the raw MSW are easily screened, meanwhile the moisture of the screened MSW without the screened kitchen garbage reduces to 30%, and the lower heating value (LHV) of the preprocessed MSW can reach 13,000 kJ/kg. The preprocessed MSW mainly consists of textiles, rubber, and plastics, etc., and is about 25% (in weight) of raw MSW with a moisture content of 60%. So the facility capacity is 50 t/d of pre-processed MSW, which is from 200 t/d raw MSW. After shredding into small pieces, the preprocessed MSW can be fed into the plasma gasification reactor by a lifting and conveying system.

Figure 1: Process flow chart of the MSW plasma gasification facility

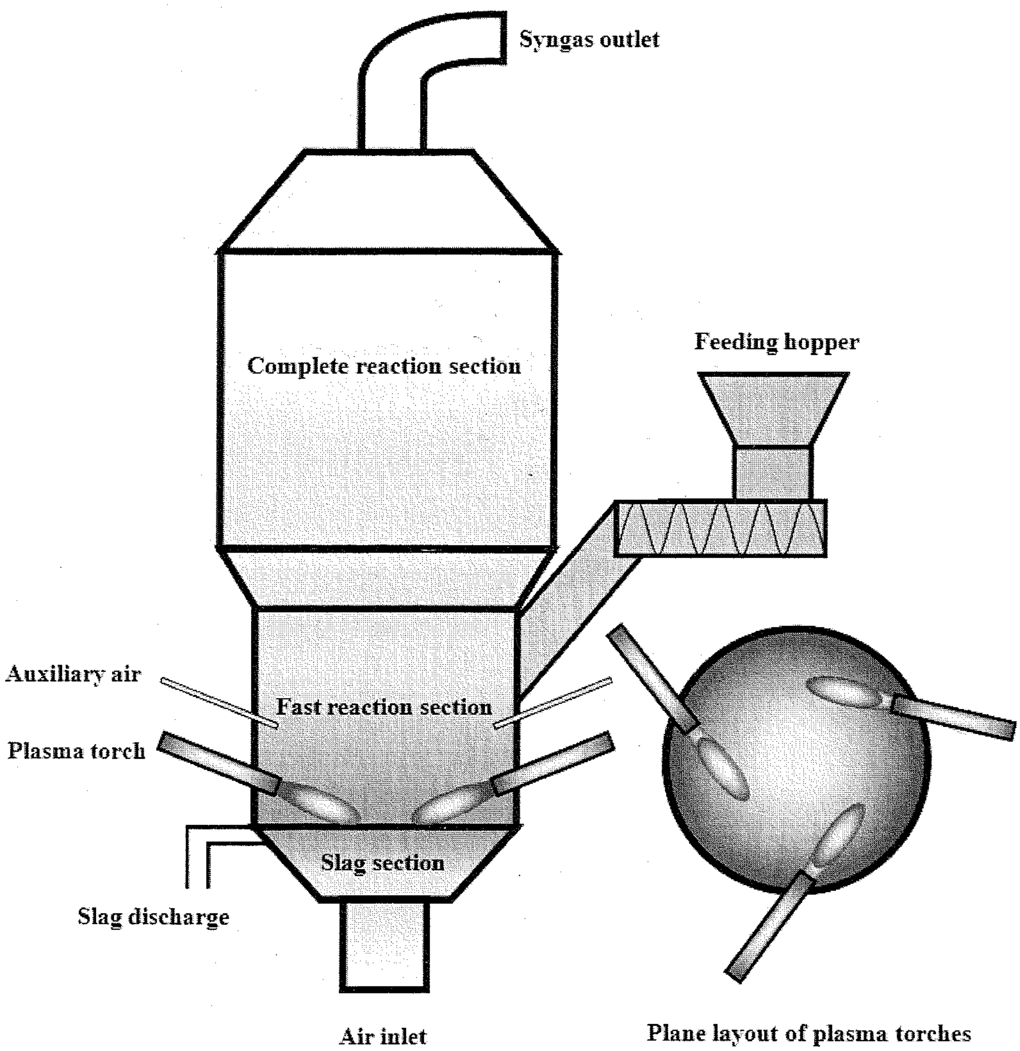


Plasma Gasification Reactor

The plasma gasification reactor is the core part of the facility. As shown in Fig.2, it is composed of a feeding system, several plasma torches, an air inlet on the bottom and several auxiliary air inlets on the side wall, and a syngas outlet.

The reaction regions in the reactor can be divided into three sections, including the slag, the fast reaction and the complete reaction. The pre-processed MSW is fed into the reactor from the feeding hopper and drops into the fast reaction section until reaching the air distributor. Under the joint effect of exothermic reaction and heating by the thermal plasma, the organics in the MSW will be decomposed and reformed into small molecular gas, syngas. The oxidant of the gasification reaction is supplied from the bottom air inlet, the plasma torches, and the auxiliary air inlets. 30% of the stoichiometrical air was supplied into reactor to get better syngas. The mass flow rate of the air from bottom air inlet should be calculated and controlled to fluidize the MSW pieces in the fast reaction section. This makes the reaction fast and stable.

Figure 2: Schematic diagram of the plasma gasification reactor



4-6 air plasma torches of 600 kW in total are used as enhanced energy sources for gasification. The torches are set at fixed angles on the horizontal plane and vertical plane to produce swirl, which can make the flow and temperature fields more homogeneously. The experimental photograph of the high power air plasma torches are shown in Fig. 3.

The products from the fast reaction section flow to the upper complete reaction section of 1,000 °C for a further complete reaction for about 5 seconds. Through an equilibrium reaction products analysis shown in Fig. 4, it can be found that the mole fraction of CO and H2 will reach the maximum when the reaction temperature is close to 1,000°C. Meanwhile, the dioxins are fully destroyed in the high temperature zone.

Figure 3: Experimental photograph of the high power air plasma torches

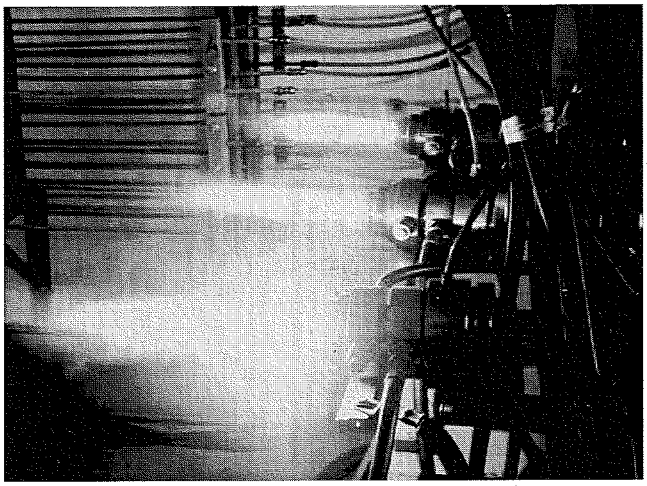
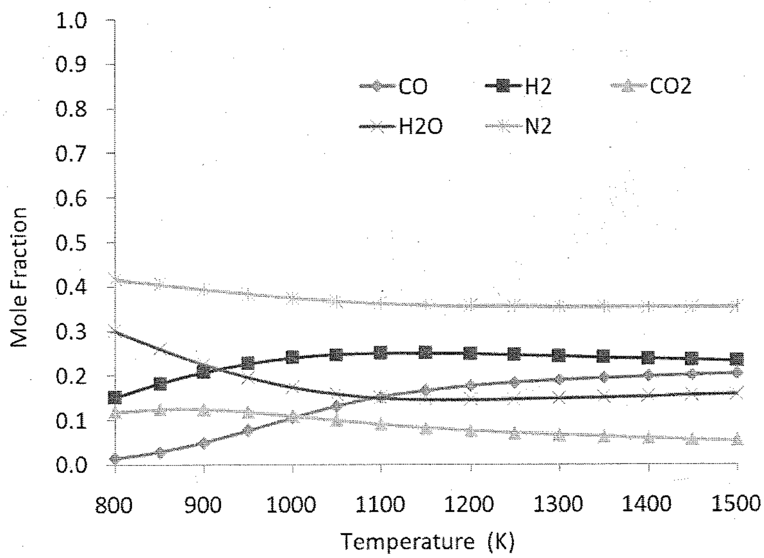


Figure 4: Mole fraction of the syngas under different gasification temperature



Syngas Cooling and Cleaning System

A special syngas-water heat exchanger is designed to recover energy from the hot syngas, and the temperature of the metal boundary beside the hot sygas could be controlled by the cooling water, which could avoid the corrosion of HCl gas under high temperature and of hydrochloric acid below the dew point. Meanwile, the cooling process duration of syngas is shorter than 0.5 second from 500°C to 200°C, so the reformation of dioxins is prevented. The steam obtained from the heat exchanger can be used in the preprocessing of the raw MSW to improve the total energy utilization efficiency.

After the cooling process, the syngas passes through a cleaning system consisting of a dry acid removal system, a bag filter, a wet acid gas scrubber, and a carbon bed absorption equipment. Through the double acid removal process, acid gases like HCl can be removed completely. Because the scrap tire is usually recycled, the concentration of sulfur in the MSW of Beijing is relatively low, so H2S and SOx produced in the gasification can be neglected. In consideration of security, an active carbon bed is set to ensure the extremely low dioxins emission. Before being supplied to the gas engine, the moisture in the syngas needs to be reduced through the cooling and condensing process. Then the syngas is stored in the gasholder, as a buffer, before feeding into the gas engines.

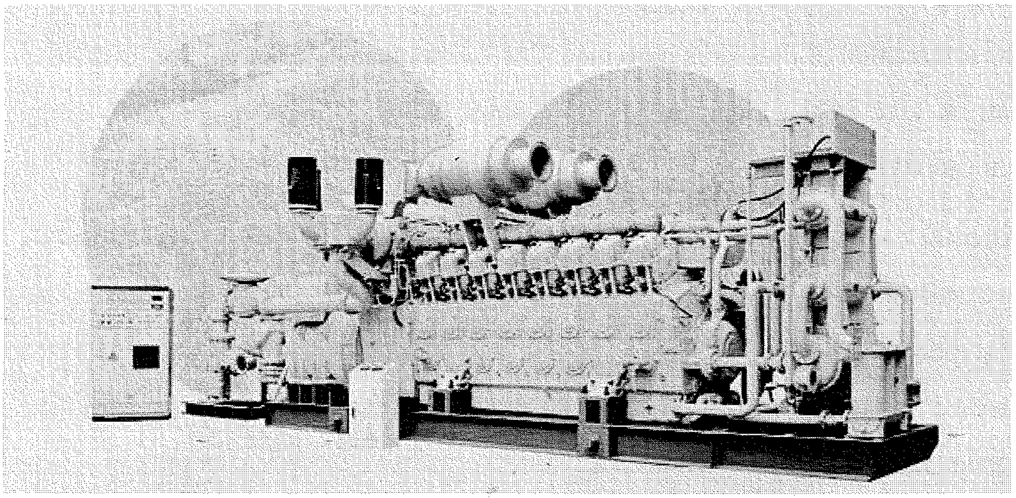
Syngas Heat and Power Cogeneration System

Custom gas engines are used to generate power from the syngas. The gas engines should be designed and adjusted carefully according to the component of the syngas. Figure 5 shows a customized gas engine made by our partner company.

For supporting a 50 t/d MSW gasification facility, 5 gas engines of 500 kW are used to generate 2.5MW electrical power. Taking away the power used by the plasma torches and other equipments, almost 1.5MW power can be sold to the electricity grid.

The mass flow rate of the steam produced by the syngas-water heat exchanger and superheated by the gas engine exhaust heat exchanger could be above 5t/h. If there is appropriate heat consumers, the benefits obtained from selling the steam are even more than selling the electricity. However, the steam has to be used to generate power by steam turbines if there is not a heat consumer. This will increase the total investment.

Figure 5: Photograph of the gas engine for power generating with syngas



ECONOMIC ANALYSIS

The total investment of the MSW plasma gasification facility can be controlled to be close to that of the MSW incineration facility with similar capacity. The total investment of the 50 t/d demo plant is approximately 11 million USD, about 7.3 million USD per MW.

In general, the electrical power generating efficiency of the gasification and gas engines system is at least 10% more than the incineration and steam cycle, which causes the gasification system to have much better economic benefits than incineration. Because of the relatively higher power generating efficiency, the investment payback period may be reduced 2 to 3 years by choosing the plasma gasification technology rather than the incineration technology.

Pre-processing of raw MSW with the steam produced from the syngas-water heat exchanger is a kind of perfect technology cooperation. The stream superheated by the exhaust of gas engines can be sold to the heat consumers or used to generate power with stream turbines, which can increase the economic benefits of the project remarkably.

CONCLUSIONS

The theoretical and engineering research on the municipal solid waste plasma gasification facility has led to the following conclusions:

(1) The plasma gasification technology is the state of the art and environmentally friendly technology for the disposal of MSW and other organic wastes.

(2) According to the component of the MSW, the moisture, mass flow rate of air, and the gasification temperature should be chosen appropriately to obtain the best energy recovery efficiency.

(3) Because the power generating efficiency of the plasma gasification facility is relatively higher than the incineration facility, the investment payback period of the treatment project will be shortened.

(4) The heat and power cogeneration will remarkably increase the economic benefits of the project and protect the natural environment.

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