Waste Management 37 (2015) 137–146

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

# A case-study of landfill minimization and material recovery via waste co-gasification in a new waste management scheme

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ARTICLE INFO

*Article history:*
Available online 30 August 2014

*Keywords:*
Gasification
Waste to energy
Municipal solid waste melting
Final landfill
Material recovery

ABSTRACT

This study evaluates municipal solid waste co-gasification technology and a new solid waste management scheme, which can minimize final landfill amounts and maximize material recycled from waste. This new scheme is considered for a region where bottom ash and incombustibles are landfilled or not allowed to be recycled due to their toxic heavy metal concentration. Waste is processed with incombustible residues and an incineration bottom ash discharged from existent conventional incinerators, using a gasification and melting technology (the Direct Melting System). The inert materials, contained in municipal solid waste, incombustibles and bottom ash, are recycled as slag and metal in this process as well as energy recovery.

Based on this new waste management scheme with a co-gasification system, a case study of municipal solid waste co-gasification was evaluated and compared with other technical solutions, such as conventional incineration, incineration with an ash melting facility under certain boundary conditions. From a technical point of view, co-gasification produced high quality slag with few harmful heavy metals, which was recycled completely without requiring any further post-treatment such as aging. As a consequence, the co-gasification system had an economical advantage over other systems because of its material recovery and minimization of the final landfill amount.

Sensitivity analyses of landfill cost, power price and inert materials in waste were also conducted. The higher the landfill costs, the greater the advantage of the co-gasification system has. The co-gasification was beneficial for landfill cost in the range of 80 Euro per ton or more. Higher power prices led to lower operation cost in each case. The inert contents in processed waste had a significant influence on the operating cost.

These results indicate that co-gasification of bottom ash and incombustibles with municipal solid waste contributes to minimizing the final landfill amount and has great possibilities maximizing material recovery and energy recovery from waste.



## 1. Introduction

Waste-to-Energy is attracting great interest in many countries, such as in Japan and in Europe. In Japan, though the volume reduction of waste has historically been the first priority in waste management, energy from waste is also becoming a great interest these days. In Europe, due to the EU landfill directive, a large number of Waste-to-Energy plants have been established to reduce landfill amounts and recover energy (European Union, 1999). On the other hand, material recovery from urban sites, which indicates the recovery of valuable materials and noble metals such as gold, copper and ferrous materials in waste including municipal solid waste (MSW), MSW bottom ash, incombustibles from recycling centers, boiler and fly ash from MSW incinerators, are also attracting considerable major interest as well as energy recovery from waste (De Boom et al., 2011).

There is also concern regarding material recovery and recycling of bottom ash, though it has long been attracting great interest. Due to intermediate temperature treatment of incineration technology, the bottom ash discharged sometimes contains harmful heavy metals such as lead, zinc and mercury. Therefore, the leaching behavior of heavy metals needs to be carefully monitored. A large body of research has been reporting on the leaching behavior of heavy metals in bottom ash and its environmental impacts (Hyks et al., 2009; Birgisdottir et al., 2007).

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http://dx.doi.org/10.1016/j.wasman.2014.07.024
0956-053X/

From the viewpoint of regulations, bottom ash recycling and utilization differ from one country to another. In some countries, it can be recycled as secondary materials after post-treatment such as aging. Aging is a long-term maturing process and harmful heavy metals in bottom ash are stabilized for two or three months. The stabilized bottom ash is recycled, mainly in road construction or as cover soil for final landfill sites. On the other hand, in some countries, such as Japan, Austria and Finland (CEWEP, 2010; ISWA, 2006), the bottom ash discharged from waste incineration facilities is not allowed to be recycled. It is mainly transported and disposed of in a landfill site. In these countries, further research or an alternative to bottom ash stabilization and material recovery from waste are needed.

A waste gasification and melting technology has the possibility of simultaneously addressing both material recovery from waste and landfill minimization. Gasification of MSW and biomass as an energy recovery method such as fixed-bed, fluidized bed, entrained or plasma gasification, has been widely researched all over the world (Arena et al., 2010; Arena and Di Gregorio, 2013a; Mastellone and Arena, 2008; Mastellone et al., 2010; Aigner et al., 2011; Pinto et al., 2008; Taylor et al., 2013; Willis et al., 2010). Waste gasification is also being researched in many countries, but there are few proven or commercial technologies. Furthermore, in many cases, limited feedstock, such as high-quality refused derived fuel (RDF), is processed in demonstration or commercial gasification plants. In addition to the above-mentioned issues, there is no significant improvement of residues discharged from developing gasification technologies. In Japan, a lot of gasification plants for MSW, including gasification and melting processes, are under commercial operation. The Direct Melting System (DMS) is a shaft-furnace type gasification and melting process and is classified as an atmospheric moving bed gasifier. The DMS has been in commercial operation since 1979 and has been operated at more than 40 plants in Japan and South Korea (Tanigaki et al., 2012, 2013a; Osada et al., 2008, 2012; Manako et al., 2007). This technology can process various kinds of waste, such as asbestos, bottom ash, clinical waste, sewage sludge or automobile shredder residues (ASR) with MSW, and can recover both energy and material from waste in one process. In this study, this material recovery from various kinds of waste via gasification and melting process (the DMS technology) is defined as co-gasification, due to the contemporary feeding of different wastes. The molten materials produced, which can be separated in inert slag and metal, can be utilized as recyclables without any further post-treatment such as aging. As a positive consequence of this waste flexibility and material recovery from waste, this technology can offer a new waste management scheme. This new waste management scheme can process MSW with other waste such as incombustibles or bottom ash from other incineration plants to maximize material recovery from waste and minimize final landfill amounts.

The objective of this study is to clarify the possibilities of the new waste management scheme using co-gasification of MSW with bottom ash and incombustible residues. Firstly, the operating data of co-gasification is evaluated using a commercial waste gasification and melting technology (DMS). The quality of slag and metal produced are also investigated to evaluate the potential for material recovery from waste. Secondly, a case study in two different waste management schemes is conducted and compared with other conventional systems: an incineration without a bottom ash melting system and with a bottom ash melting system. Lastly, sensitivity analyses are also conducted with variation of the landfill gate fee, power price and inert contents of waste to be processed. Some operation performances of the DMS have already been reported (Osada et al., 2008, 2012; Manako et al., 2007; Tanigaki et al., 2012, 2013a). However, this is the first report which describes the main economic aspects of co-gasification of MSW and other waste.

## 2. Methodology

### 2.1. Process description

The process is described in previous papers (Tanigaki et al., 2012, 2013a). The plant mainly consists of an MSW charging system, a gasifier, a combustion chamber, a boiler and a flue gas cleaning system.

One of the advantages of the DMS process is that no pretreatment of waste is required, which differs from other gasification technologies such as a fluidized bed gasifier. The maximum waste size to be processed is approximately 800 mm. Waste is directly charged into a gasifier from the top, together with coke and limestone which function as a reducing agent and a viscosity regulator, respectively. Due to the addition of the limestone, the viscosity of the melt is adjusted properly and the melt is discharged smoothly from the bottom of the furnace without any clogging. Oxygen-enriched air is blown at the bottom of the furnace via tuyere. The gasifier consists of three main parts: a drying and preheating zone, a thermal decomposition zone and a combustion and melting zone. waste is gradually dried and preheated in the upper section (the drying and preheating zone). Combustible waste is thermally decomposed in the second zone and syngas is discharged from the top of the gasifier. The syngas, which mainly contains carbon monoxide, carbon dioxide, hydrogen, methane, hydrocarbons and nitrogen, is transferred to the combustion chamber in the downstream of the gasifier and then completely burned. Incombustibles descend to the combustion and melting zone (1000-1800 °C) at the bottom and are melted with the heat generated by coke burning. Gasification reactions such as water-gas-shift, water-gas and boudouard reactions mainly take place in this zone of the gasifier. Molten materials are intermittently discharged from a tap hole, quenched with water, and magnetically separated into slag and metal. Due to high-temperature and reducing atmosphere generated by coke burning at the bottom of the gasifier, toxic heavy metals are volatilized and few toxic heavy metals remain in molten materials, which can be widely recycled. Because of this, the DMS can maximize material recovery from waste without any further pre- and post-treatment such as drying, crashing or aging.

The combustible dust discharged from the gasification and melting furnace is captured by the cyclone installed in the downstream of the furnace. The captured char is injected into the furnace via tuyere. This system has three major advantages (Manako et al., 2007). Firstly, the coke amount is reduced because the injected combustible dust reacts with oxygen-rich blown air as a coke substitute. Secondly, the combustion condition in the combustion chamber is improved because of gas combustion with little dust. Lastly, dust is captured by the cyclone and this reduces fly ash amount in the downstream. In addition to this technology, an air pre-heating technology for combustible dust injection can reduce the coke amount (Tanigaki et al., 2013b). This technology has improved the reaction kinetics of the char injected into the gasifier. As a result, the coke consumption is reduced between 2% and 4% with the application of these technologies. Biomass coke utilization with these developed technologies can also reduce the environmental impacts such as global warming (Tanigaki et al., 2012).

The syngas produced in the gasifier is combusted in the combustion chamber by air. Heat is recovered by a steam boiler and power is generated by a steam turbine. Flue gas cleaning system is similar to that of incineration technologies (Tanigaki et al., 2013a). That generally consists of a quencher, a baghouse, an ID-fan and a selective catalytic reduction (SCR). Flue gas is cooled to