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Application of thermal plasma technology for the treatment of solid wastes in China: An overview

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ABSTRACT

With its enormous social and economical development, China is now experiencing a rapid increase in solid wastes generation and growing pressure for solid wastes management. Today solid wastes in China are mainly managed by a combination of landfill, incineration, and composting. Within different possible treatment routes, thermal plasma technology (TPT) offers the advantages of efficiently gasifying the organic contents of solid wastes into syngas that can be used for heat and power generation, and vitrifying the inorganics simultaneously into glassy slag with very low leachabilities. This process makes it feasible for near-zero emission into the environment while making use of all the useful components. Encouraged by the industrial operations of solid wastes treatment plants using TPT in some countries, several plasma demonstration projects have already been undertaken in China. This paper provides a preliminary overview of the current laboratory researches and industrial developments status of TPT for the treatment of solid wastes in China and analyzes the existing challenges. Furthermore, the future prospects for TPT in China are also discussed.

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1. Introduction

As the second largest economy in the world, China has become the largest solid wastes generator in the world since 2004 owing to

the unprecedented rate of urbanization, industrialization and steadily improving living standards (Chen et al., 2014). According to the Chinese law on the solid wastes prevention and control of environment pollution, solid wastes are classified into three types: municipal solid waste (MSW), industrial solid waste (ISW), and

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hazardous waste (HW). In 2010 (China Statistical Yearbook, 2011), China produced 158.0 million tons of MSW (the total quantity collected and transported), 2409.4 million tons of ISW, and 15.9 million tons of HW, whereas in 2014 (China Statistical Yearbook, 2015), the survey estimates were 178.6 million tons of MSW, 3256.2 million tons of ISW, and 36.3 million tons of HW. Hence, the solids production increased by 13%, 35%, and 128%, respectively in five years, which means solid wastes in China grow so fast that should be a cause for serious concerns to all.

The harmless management of solid wastes is very important to build a resource-saving and eco-friendly society (Zhao et al., 2016a, b). In response, the Chinese government is seeking effective ways of waste treatment processes during 'the 13th Five-Year Plan' period (2016–2020). Today solid wastes in China are managed by a combination of landfill, composting, and thermal treatment. Among them, sanitary landfill is the dominant form for solids disposal. However, this method suffers from the problems of releasing toxics and occupying vast expanses of land. Composting is the biological decomposition of organic wastes by bacteria, fungi, worms and other organisms under controlled aerobic conditions (Sánchez-García et al., 2015). The drawbacks of this process are the slow degradation rate and the limitation to only organics (Ojha et al., 2012). Hence landfill and composting are neither sufficient nor efficient solutions.

Thermal waste processing technologies, including incineration, pyrolysis, gasification, hold promises in more efficient treatment and energy recovery from the wastes. In recent years, interest in the utilization of advanced thermal plasma technology (TPT), as one of the thermal processing technologies, for wastes treatment has increased enormously (Agon et al., 2016; Materazzi et al., 2013, 2015; Morrin et al., 2012, 2014; Tang et al., 2010; Wang et al., 2010), primarily because of high destruction efficiency and environmental compatibility. By gasifying the combustible parts of the solids into syngas for heat and power generation, and vitrifying the noncombustible parts simultaneously into dense, inert, leach-resistant vitrified slags, pollutants emission could be reduced to almost zero and valorization of all the components of the wastes could be achieved.

For similar reasons, plasma technology is gaining increasing popularity in China. This paper provides an overview of the current status of TPT for the treatment of solid wastes in China. The major barriers facing the growth of plasma industry are discussed and the perspective of plasma technology in China is also presented.

2. Background of TPT

2.1. Brief overview of TPT

Plasma is considered to be the fourth state of matter, consisting of a mixture of electrons, ions and neutral particles, although overall it is electrically neutral (Jiang et al., 2014). Plasma can be categorised into three types, thermal plasma, cold plasma and warm (intermediate) plasma. Thermal plasma attains high temperatures, although not as high as 'hot plasma' found in thermo-nuclear research and astrophysics, and is in thermal equilibrium (Ruj and Ghosh, 2014). Bogaerts et al. (2002) classified this type of plasma as fusion plasma, a type of plasma that is commonly found in stars with a temperature range of 4000–20,000 K. Thermal plasma has been traditionally used in the treatment of a broad variety of wastes (Gomez et al., 2009). The other two types of plasma are classified as non-thermal equilibrium plasma. Two basic kinds of plasma configurations i.e. transferred and non-transferred arc torches can be used in the treatment of solid wastes. In a non-transferred arc torch, the plasma arc is generated in a torch body whereby a gas is converted into plasma which is applied to the waste, producing syngas and slag. In the second case, the

substance to be processed is placed in an electrically grounded metallic vessel and acts as anode, hence the reacting material should be an electrically conductive material (Huang and Tang, 2007). Non-transferred arc torch is the more commonly used device for the waste disposal.

The plasma generator can be conjuncted with reactor through two modes: (1) One is a single-stage reactor that incorporates the plasma reactor and plasma torches into one body; (2) The another is a two-stage reactor that a conventional reactor is followed by a plasma converter, in which the crude syngas and the solid residue from the former step are reformed. The first case is the more commonly used mode. The plasma jets are located at either the bottom or the top of the reactor, and waste is heated directly by plasma jets. In the second case, the plasma heat is used to provide the heat to 'polish' the crude syngas, and/or to vitrify the solid residues derived from the conventional thermal process (Fourcault et al., 2010). Compared to a two-stage plasma system, the produced syngas from the single-stage reactor showed more favourable characteristics, while the recovery of the solid residues as a vitrified slag is an advantage of the two-stage set-up (Agon et al., 2016; Cao et al., 2014b).

2.2. Solid wastes management by TPT

Plasma conversion technology is a multi-stage process. The actual plant design and configuration of plasma technology for solid wastes treatment varies considerably between technology suppliers. However, a plasma plant typically consists of the following key elements: (a) Pretreatment; (b) Plasma gasification/vitrification; (c) Off-gas clean-up; (d) Slag recovery; and (e) Energy recovery. A typical configuration of a plasma treatment process is illustrated in Fig. 1.

The first step is to process the feedstock to make it uniform and dry, and have the valuable recyclables sorted out, i.e. sorting and size reduction of the feedstock. The waste is then delivered to the plasma reactor, which operates in a high-temperature and oxygen-deprived condition. The organics of the solids are converted into syngas with a conversion rate of greater than 99% (Yang et al., 2011) in which process the elements C, H and O are mainly converted into hydrogen and carbon monoxide. The inorganics and minerals of the solids that are not broken down go through a phase change (solid to liquid), ultimately producing a benign vitrified slag. The syngas that leaves the reactor has a temperature between 1273 K and 1473 K (Gandhi, 2015). It is passed through a heat exchanger system where the heat from the syngas is recovered and used to generate steam from water. This steam is used to run the steam turbines to generate electricity. The cooled syngas (approximately 673 K) is purified and can be valorized for both energetic (heat and/or electricity) and chemical (ammonia, hydrogen or liquid hydrocarbons) end-purposes (Fabry et al., 2013).

3. TPT exploration in China

3.1. Brief overview of TPT for solid wastes management around the world

Table 1 lists some of the typical solid wastes TPT treatment facilities around the world. Most facilities are established in U.S. and Japan. Generally speaking, these plants operate successfully on a single, low moisture feedstock, the composition and characteristics of which are well understood and do not vary much over time (such as MSW incinerator fly ash or bottom ash – MSWI FA or BA, HW, and medical waste). These systems range in capacity from 1 t/d to 100 t/d, with most in the range of 5–30 t/d. MSW, on the

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