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Plasma methods for metals recovery from metal–containing waste

Du Changming *, Shang Chao, Xiangjie Gong, Wang Ting, Wei Xiange *

School of Environmental Science and Engineering, Sun Yat–sen University, Guangzhou 510275, China

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ABSTRACT

Metal–containing waste, a kind of new wastes, has a great potential for recycling and is also difficult to deal with. Many countries pay more and more attention to develop the metal recovery process and equipment of this kind of waste as raw material, so as to solve the environmental pollution and comprehensively utilize the discarded metal resources. Plasma processing is an efficient and environmentally friendly way for metal–containing waste. This review mainly discuss various metal–containing waste types, such as printed circuit boards (PCBs), red mud, galvanic sludge, Zircon, aluminium dross and incinerated ash, and the corresponding plasma methods, which include DC extended transferred arc plasma reactor, DC non-transferred arc plasma torch, RF thermal plasma reactor and argon and argon–hydrogen plasma jets. In addition, the plasma arc melting technology has a better purification effect on the extraction of useful metals from metal–containing wastes, a great capacity of volume reduction of waste materials, and a low leaching toxicity of solid slag, which can also be used to deal with all kinds of metal waste materials, having a wide range of applications.

Contents

1. Metal–containing waste and disposal methods

As more and more solid waste is generated in industrial production and daily life, their types are also increasing. Metal–containing waste is a kind of new wastes, which comes from circuit boards of electronic products, glass fiber refractory coating, steel plant dust,

* Corresponding authors.
E-mail addresses: duchm@mail.sysu.edu.cn (D. Changming), 1220805600@qq.com (X. Gong), eeswxg@mail.sysu.edu.cn (W. Xiange).

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arc furnace dust, electroplating and tanning industry sludge, metal–containing soil phytoremediation plant and so on.

According to the different industries, the treatments of metal waste have different ways. For example, pyrometallurgical and hydrometallurgical treatment is generally used to recover valuable metals from electronic products. Pyrometallurgical treatment means thermal chemical treatment, such as incineration, pyrolysis and melting (Song and Xu, 2008; Ya et al., 2016; Hall and Williams, 2007). Thermal chemical treatment tends to produce toxic gases dioxins and furans. However, hydrometallurgical treatment is easy to produce a large amount of acidic waste liquid (Oishi et al., 2007). The main treatment methods for electroplating sludge include curing, stabilization and heat treatment (Wu et al., 2004; Zhang et al., 2004). Hyperaccumulators are mainly treated with thermochemical methods (Li et al., 2005; Zhong et al., 2011). Landfill, which is the final disposal of waste, requires more stringently for landfill waste. Because of the limited land resources, it is necessary to maximize the volume reduction of wastes and to form stable, leachable end products (Wei and Liu, 2009), which can be handled in the garbage filling site.

Plasma treatment technology is an efficient and safe waste disposal method. Plasma, with high energy density and high temperature, is the fourth state of matter, which is generated in highly ionized gas (Du et al., 2015). High–temperature plasma smelting, instead of incineration, can destroy harmful organic compounds, while producing less dioxin and furans. At the same time, the heat generated by the plasma can degrade organic pollutants, and the inorganic material can be melted into ceramic slag (Huang et al., 2003). The properties of molten slag are relatively stable and less harmful. However, the disadvantage of the high–temperature melting is that the volatile metal is not liable to remain in the slag of the furnace. Another drawback is that the off–gas from the high–temperature furnace produces dioxins and furans during the cooling phase (Yang and Kim, 2004). Therefore, we should select appropriate technology of exhaust gas treatment.

From Sections 3–11 in this manuscript, various waste types and the corresponding plasma methods will be discussed. In order to increase the continuity of the topics, a table to describe the specific waste types and some sort of plasma methods which are supposed to be appropriate for theirs treatment/recovery is shown as Table 1.

2. Plasma classification and plasma melting mechanism

To explain the difference of plasma technologies in Table 1, the general classification of plasma and several technologies appearing

Table 1
Waste types and the corresponding plasma methods.

Chapter	Waste types	Corresponding plasma methods	Reference
3. Plasma pyrolysis of electronic waste	Waste circuit boards	Thermal plasma processing waste incineration furnace with DC non-transferred arc plasma torch	Wang et al. (2013)
3. Plasma pyrolysis of electronic waste	Printed circuit boards (PCBs)	35 kW dc extended transferred arc plasma reactor	Rath et al. (2012)
3. Plasma pyrolysis of electronic waste	The copper-clad laminate (CCL)	A 30 kW DC plasma torch	Mitrasinovic et al. (2011)
4. Using plasma to recover iron from red mud	Red mud	A 35 kW DC extended transferred arc plasma reactor.	Rath et al. (2013)
4. Using plasma to recover iron from red mud	Red mud	A plasma arc furnace	Rath et al. (2011)
5.Low–level radioactive waste treatment	Low–level radioactive waste	A plasma arc melting system, comprising a graphite electrode plasma melting furnace, a direct–fired incinerator and an exhaust gas treatment system.	Yang and Kim (2004)
6. Processing, treatment, and recovery of metals resources of electroplating sludge	Powdered electroplating sludge	DC non-transferred arc plasma	Ramachandran and Kikukawa (2000)
6. Processing, treatment, and recovery of metals resources of electroplating sludge	Galvanic sludge	A DC non-transferred arc plasma torch and a DC transferred arc plasma torch	Anelise et al. (2014)
7. Purification of refractory metals	Commercial terbium metal	Plasma arc melting furnace	Li et al. (2015)
7. Purification of refractory metals	Commercial Ti sponges	A laboratory-scale plasma arc furnace equipped with a transferred arc type plasma torch	Mimura et al. (2010)
7. Purification of refractory metals	Fe, Cr, Ti, and V metals	A plasma arc furnace equipped with a transferred arc type plasma torch	Elanski et al. (2006)
8. Metallurgical waste and ore decomposition to recover metals	Zircon	A low power transferred arc plasma torch	Yugeswaran et al. (2015)
8. Metallurgical waste and ore decomposition to recover metals	Zircon	A DC plasma torch operating	Mcpherson and Shafer (1984)
8. Metallurgical waste and ore decomposition to recover metals	A dust separated from the flue gas of a Siemens–Martin furnace (SMD) and a sludge from the hot galvanizing of steel products (HGS),	An RF Thermal Plasma Reactor	Mohai et al. (2001)
9. The recovery of metal from slag	Aluminium dross	A 300 kW plasma torch	Heberlein and Murphy (2008)
9. The recovery of metal from slag	Aluminium dross	A 600 kW rotary arc furnace	Drouet et al. (1995)
10. Recovery of metal in the dust	DRI (Direct reduction iron)	A pilot-scale DC plasma-arc furnace	Jones (1993)
11. Treatment of other metal containing material	SiO2-Al2O3 mixture	Argon and argon-hydrogen plasma jets	Watanabe et al. (1999)
11. Treatment of other metal containing material	The fly ash, sludge, and glass wastes having the weight ratio of 1:1:2	The plasma melting chamber at the temperature of 1773 K	Tuan et al. (2012)
11. Treatment of other metal containing material	Incinerated ash	A 100 kW non-transferred plasma torch	Cheng et al. (2002)

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