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The status and progress of resource utilization technology of e-waste pollution in China

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Abstract

In this paper, the current status and the characteristics of e-waste were presented. The hazards of electronic wastes, significance of their recycle, resource utilization technology at home and aboard are summarized in this paper. Several recycling methods were introduced such as recycling of metals, plastics and glass, etc. The way of comprehensive utilization to e-waste in China was pointed out.

Keywords: e-waste; status; resource utilization technology; recycling;

1. Introduction

Electronic-waste (e-waste) refers to end-of-life electronic products including computers, printers, photocopy machines, television sets, mobile phones, and toys, which are made of sophisticated blends of plastics, metals, among other materials [1]. Technological innovation and intense marketing strategies engender a rapid turnover of electrical and electronic devices. The global market for electrical and electronic equipment continues to expand, while the lifespan of many products becomes shorter [2]. The current global production of E-waste is estimated to be 20－25 million tonnes per year, with most E-waste being produced in Europe, the United States and Australasia. In Europe e-waste is increasing at three to five percent a year, almost three times faster than the total waste stream. Developing countries are also expected to triple their e-waste production over the next five years [3]. China, Eastern Europe and Latin America will become major E-waste producers in the next ten years [4, 5]. E-waste is the fastest

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growing type of solid waste generated in the world. Consequently, large amounts of "e-waste" are constantly generated worldwide, posing an increasing global challenge for their disposal [6].

2. Characteristics and Damages of E-waste

E-Waste is chemically and physically distinct from other forms of municipal or industrial waste; it contains both valuable and hazardous materials that require special handling and recycling methods to avoid environmental contamination and detrimental effects on human health.

2.1. Material composition of e-waste

The diverse range of materials found in e-waste makes it difficult to give a generalised material composition for the entire waste stream [7]. However, most studies examine five categories of materials: ferrous metals, non-ferrous metals, glass, plastics and other materials. Iron and steel are the most common materials found in EEE (by weight) and account for almost half of the total weight of e-waste. Plastics are the second largest component by weight, representing -21% of e-waste. Non-ferrous metals, including precious metals, represent -13% of the total weight of e-waste (with copper accounting for 7%). And the other constituents like rubber, concrete and ceramics represent -16% [8].

2.2. The duality of e-waste

The e-waste has duality. One hand, many of the materials which e-waste contains are highly toxic, such as chlorinated and brominated substances, toxic metals, photoactive and biologically active materials, acids, plastics and plastic additives [9]. With these hazardous elements, e-waste can cause serious environmental problems during disposal if not properly pretreated. For example, the cadmium from one mobile phone battery is sufficient to pollute 600,000 l of water [10, 11]. On the other hand, the e-waste can be regarded as a resource of valuable metals such as copper, aluminium and gold. From the point of material composition, electronic waste can be defined as a mixture of various metals, particularly copper, aluminum, and steel, attached to, covered with, or mixed with various types of plastics and ceramics [10]. Precious metals have a wide application in the manufacture of electronic appliances, serving as contact materials due to their high chemical stability and their good conducting properties. Platinum group metals are used among other things in switching contacts (relays, switches) or as sensors to ascertain the electrical measurand as a function of the temperature.

3. The Status of E-waste in China

China is already the second largest generator of e-waste in the world, with 2.3 million tons generated domestically each year [12]. Meanwhile, China appears to be the largest dumping site for e-waste in the world. About 50－80% of the global e-waste is legally or illegally imported to Asia, 90% of which is designated for China [13, 14].

The e-waste recycled in China comes mainly from three sources: consumption, importation and production [15]. The constant raise of domestic EEE consumption leads to a corresponding, time-delayed increase in e-waste, meanwhile we should also notice that today there is still a significant rural－urban difference in the possession levels of major EEEs [16, 17]. Wang et al. [18] have estimated the e-waste generation of five EE products in China. According to their study, between 2008 and 2012, there is a predicted sharp rise of obsolete personal computers (PCs), televisions (TVs) and air-conditioners, with the amount of obsolete PCs, TVs and air-conditioners reaching 93.36 million units, 74.31 million units and

63.9 million units, respectively in 2012. While refrigerators and washing machines are estimated to have more moderate obsolescence rates, the quantities of discarded refrigerators and washing machines also almost doubled and trebled within the defined eleven years from 2001 to 2012.

At the same time, illegal imports of used EE products or WEEE from overseas has been added to the volume of e-waste being treated in China. China now appears to be the largest dumping site of e-waste in the world, receiving continuously e-waste shipments from US, Europe and neighboring Asian countries including South Korea and Japan[19, 20]. Transboundary movement of e-waste is primarily profit-driven. Recyclers and waste brokers are taking advantages of the lower recycling costs and higher revenues accruing from machine reuse in China; meanwhile also trying to evade the entitled disposal responsibilities in home countries. The legislation gaps in e-waste management between countries and relatively weak custom control in China also provide opportunities for illegal entry of e-waste into the country.

The third source contributing to the huge e-waste amount is the electronics industry, being a major economic driver of China and one of the fastest growing sectors since the 1980s[21]. Exports from the EEE sector earned China US$227.46 billion in 2003, accounting for 51.9% of the country’s total export value[22]. Today, China is the world’s largest producer, consumer and exporter of EEEs. Consequently, scraps generated during EE manufacturing processes are an unignorable part of the domestic e-waste streams, though the total volume of production e-waste is much smaller and easier to control compared to those coming from domestic EEE consumptions and illegal imports.

4. Resource Utilization Technology of E-waste

Nowadays, recycling processes became more and more important mostly due to the impressive increase in the production of wastes and to growing attention to the environmental safeguard [23]. Electronic waste is made of a mixture of various metals, particularly copper, aluminium and steel, mixed with various types of plastics, glass fibre-reinforced epoxy resin and ceramics [24]. Recycling of e-waste is an important subject not only from the point of waste treatment but also from the recovery aspect of valuable materials [25]. Many researches show that the major materials in e-waste are metals, plastics, and glass. Recycling different materials need to have different methods. So in this paper, the recycling methods of different components at home and abroad were introduced.

4.1. Recycling of Metals

E-waste contain precious metals, making the recycling of these wastes economically interesting, but also some critical metals and their recycling leads to resource conservation.

The recovery of precious metals from electronic waste is now carried out by physical separation processes[26], pyrometallurgical processing, hydrometallurgical processing, and biometallurgical processing[13] [10, 27]. High temperature Pyrometallurgy, i.e., 1200 ◦C, as usual technology requires high investments. NaOH can be used as slag formation material to separate metal from slag and decrease the melting temperature[28]. Hydrometallurgical processes require various steps, including a series of acid or caustic as leaching media for solid material, followed by various separation and purification procedures [29]. However, if hydrometallurgy is now demonstrated as sustainable route for waste processing, unfortunately, extraction of precious metals and mainly gold is only possible in cyanide media.

Therefore, the traditional technologies cannot meet the future requirements of industry because of environmental contamination, high cost and low efficiency. Two recycling processes at industrial scale, i.e., Pyrocom and Haloclean, are used presently [27, 30]. Developing new clean technologies for recycling valuable resources from WPCBs is of great significance, with two main objectives: saving in energy (using recycled materials in place of virgin materials results in significant energy savings) and reduction in pollutions. Flandinet [31] reported on a new approach for recycling waste printed circuit boards (WPCBs)with molten salts and specifically molten KOH – NaOH eutectic. This method is efficient for recovering a copper-rich metallic fraction, which is, moreover, cleared of plastics and glasses. With this method, the metallic fraction, which contained copper, and all the precious metals present in the waste, were recovered, with no dissolution or melting phenomena, Moreover, molten hydroxides, due to their high basicity, dissolved and trapped many gases such as halogens or carbon monoxide and dioxide. Finally, the flue gas contained almost 30% of hydrogen, a gas which can be collected as fuel gas or as a chemical feedstock. It should be pointed out that, to reduce the consumption of fresh salt, a recycling system can be included. In a pilot plant, the metallic fraction can be easily separated from the molten salt, using an appropriate sieve, and the molten NaOH – KOH mixture be transferred to the reaction vessel.

4.2. Recycling of Plastics

E-waste contains from 10% to 30% plastics according to Taurino et al.[23] [32]. Plastics must therefore be included in the recovery or material recycling streams. After metals, plastics have the greatest potential salvage value from electronic products. The plastics used in electronic products are mainly ‘engineering thermoplastics’, which have high intrinsic value. When pelletized, these engineering thermoplastics typically sell for dollars-per-pound as compared to cents-per-pound for bottle and container-grade plastics.

Recycling of WEEE plastics is a big challenge, mainly due to two reasons: First, the plastics waste fraction of WEEE consists of more than 15 different polymer types. Second, a large part of WEEE plastics contain brominated flame retardants (BFRs), including polybrominated biphenyls (PBB) and polybrominated diphenyl ether (PBDE). These BFRs have attracted tremendous attention over the past decade. Flame retardants are substances used in plastics, textiles, electronic circuitry, and other materials to prevent them from catching fire [33], in particular BFRs are incorporated into plastics either through reaction or addition.

Achilias et al.[34] reported the work on the chemical recycling of three types of polymers from WEEE after the chemical identification of each one by FTIR and DSC. Other most common approaches to plastics recycling include incineration to produce energy, and mechanical recycling where plastic waste is reused in manufacturing. While mechanical recycling process of single thermoplastic polymeric materials, namely HDPE and LDPE, has developed to a reasonable level, recycling of ABS/PC thermoplastics has not progressed and remained somewhat unattractive. This is because plastics recovered from end-of-life electronics contain a mix of thermoplastics such as polycarbonate (PC), ABS and their blends constitute about 56 wt.% of the recovered plastics. Generally, mixed recycled polymers exhibit weak mechanical properties and show unpredictable rheological properties which preclude their usage in high value applications. Then for mechanical recycling processes, to make recycled material suitable for high value applications, two strategies could be employed. In the first strategy, additives such as impact modifiers are added to recycled resin in order to improve mechanical properties[35]. The second strategy is to mix appropriate quantity of recycled material with the virgin material in order to obtain a blend that exhibits a good balance between properties and processability properties which allows its reuse and upgrading is absolutely necessary in a recycled material. Blending techniques are an interesting solution to obtain synergetic properties but they are limited by compatibility considerations. Several studies reported the rheological and mechanical properties of recycled PC and ABS of various purity levels recovered from computers and showed that impurity level has a very strong effect on impact strength and elongation at break.

4.3. Recycling of glass

There are two recycling methods of glass from e-waste. One is Glass-to-glass recycling and the other is glass to lead recycling [36]. Glass-to-glass is considered a closed loop recycling process because glass that is collected is used as a raw material for new CRTs. Using recycled CRT glass can create some risk to the glass manufacturing company due to the difficulty in determining the exact composition of recycled glass. The risk involved with using glass with an unknown composition is that a small addition of the wrong composition can contaminate the contents of an entire glass furnace and lead to changes in glass properties. To correct an incorrect glass composition can require the glass furnace to be shut down for 3–4 days [37]. There are several benefits to the glass-to-glass process. First, recycled cullet can replace the virgin materials at an equal or lower cost and improve the efficiency of the furnace, which lowers the energy consumption for making CRT glass. Also, this process can improve the quality of the output glass and reduce emissions from the glass making process, because recycled glass already has high purity. The value of cullet to a primary CRT glass manufacturer is igher than that to the lead smelter, which is the other glass recycling method.

There are several glass-to-glass recyclers in the U.S., such as NxTCycle, Dlubak Glass, and Envirocycle. For example, Envirocycle produces 400 tones of cullet per week. The end-market for CRT cullet is Techneglas, which in 2001 manufactured the glass components for more than 235 million TV CRTs [38]. Techneglas estimates that the prescent recycled glass in new CRTs could reach a level of 40 wt.%, if high-quality glass cullet could be provided in sufficient quantity. But there are barriers for glass-to-glass. The barriers include the difficulty in identifying glass composition, the cost of CRT demanufacturing, the cost and complexity of the required collection infrastructure, and insufficient supply of recycled cullet. Overall, this is a labor intensive and expensive process compared to lead smelting, discussed below.

In the glass-to-lead recycling process, metallic lead (Pb) and copper (Cu) are separated and recovered from the CRT glass through a smelting process. Although there are variations, CRTs generally contain 0.5–5 kg of lead (in the glass), which is used in the glass to protect people from exposure to X-ray emissions, and 1–2.3 kg of copper (in the yoke). Before smelting, CRTs are shredded and the metals and plastics are separated. Recovered CRT glass goes to the lead smelter. The glass-to-lead recycling process has a high overall throughput. However, this process reduces the value of high quality glass.

In North America, there are a limited number of smelters for CRT glass, which leads to the need for long-distance transport for the CRTs, which is very expensive. For instance, in California, CRTs can be sent to shredding facilities, such as ECS. HMR and Kinsbursky Brothers,10 Inc. provide CRT crushing services, whereas Micrometallics11 ships CRTs to the Noranda smelter. Although there are several secondary smelters in North America, the major end-markets for glass-to-lead CRTs are Doe Run and Noranda[39, 40].

Furthermore, when compared to glass-to-lead, the glass-to-glass process reduces the regulatory burden by treating CRTs as universal waste instead of as hazardous waste, which would be governed by the Resource Conservation and Recovery Act (RCRA) [37].

5. Conclusions

With rapid economic growth and tourism industry development over the past several decades, accompanied by the entry of more and more electronic products into residents' households, e-waste issues have arisen. Recycling of e-waste in China is still in its initial stages, and e-waste problems have become a potential threat to the environment and human health. Although there are some recycling methods to reuse the different components in the e-waste, they are not sufficient. We still try our best to develop new technologies to effectively utilize the useful materials in the e-waste, which won't cause environmental pollutions.

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