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An evaluation of recycling schemes for waste dry batteries – a simulation approach

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ABSTRACT

Shorter product life cycles are causing increase in the volume of electrical and electronic equipment waste and batteries are an important functional component of these. There are still batteries in use today which contain mercury, lead and nickel. These heavy metals are toxic and harmful to both the environment and human and have to be disposed of by proper processes. In Taiwan, waste dry battery recycling is managed by the Recycling Fund Management Board. Producers only have to pay advance disposal fees (ADFs). Many countries have adopted the concept of Extended Producer Responsibility (EPR), which requires the product manufacturer to assume responsibility for recycling and final disposal in compliance with the related laws. In this study the effects of three different recycling schemes under different recycling situations is investigated by simulation. System output data is collected under different recycling situations, and the cost effectiveness is determined and analyzed. The investigations showed the Producer Responsibility Organizations combined with a deposit system revealed the most cost effectiveness. This would seem to be a better scheme in terms of cost effectiveness for implementing in Taiwan.

1. Introduction

Improvements in the quality of life and general lifestyle around the world have resulted in increased consumption, a consequent increase in large scale production, and the ensuing generation of huge volumes of waste. Countries everywhere are working on waste reduction and effective control measures. Waste treatment has become the focus for waste reduction rather than environmental health. In response to this situation, the European Community published two directives, WEEE and RoHS, to limit the hazardous substance content of electrical and electronic equipment (EEE) within the European Union (European Commission, 2003a; European Commission, 2003b). These directives require the manufacturer of a product to assume financial responsibility for waste electrical and electronic equipment (WEEE) and its recycling and final disposal. These two directives embrace the spirit of Extended Producer Responsibility (EPR). The EU expects producers re-design their products, increase the recycling rate and decrease the environmental impact during final disposal.

The increasing amount of EEE waste from shorter product life cycles includes an inordinate volume of batteries. It has been estimated that 3 billion batteries are sold per year in the USA alone, which is equal to US$2.5 billion. In Europe 5 billion batteries were produced in 2000 (Bertuol et al., 2006). Another important factor in relation to the amount spent on batteries is that consumers very often change their cell phones before the end of their useful lives. This is the result of the continued development of new technology. Each new cell phone generation presents advantages in weight and size reduction as well as many new and better accessories such as radios, cameras, and so on and this means large numbers of batteries are discarded before their useful lives end. In addition, more and more batteries are being produced because the numbers being consumed are rising every year.

First- and second-grade batteries must be discarded in compliance with WEEE and, as mentioned before, there are still batteries in use that contain mercury, lead and nickel that are harmful to both human life and the environment. To prevent

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pollution of the environment, the EU published a battery directive (2006/66/EC) on batteries and accumulators that repealed directive 91/157/EEC) to minimize the negative impact of waste batteries on the environment (European Commission, 2006).

In Taiwan, waste dry battery recycling is managed by the Recycling Fund Management Board to which producers pay an advanced disposal fee. Many countries around the world have adopted the concept of Extended Producer Responsibility (EPR), requiring that manufacturers establish or join a recycling scheme and EPR represents the main spirit and principle of recycling nowadays. Chiu (2010) pointed out many existing problems for current waste dry battery recycling processes in Taiwan as follows: 1) as both executor and supervisor, the Recycling Fund Management Board cannot censure themselves when a target is not reached. 2) under a scheme of zero waste, the amount of recycled items will increase. 3) increases in audit costs for false payments to producers. 4) need large workforce and administrative costs on auditing. 5) limited by government and regulations, no innovation or flexible decision making. And 6) producers are not involved in the system, and have no incentive to help with recycling.

We have taken the waste dry battery recycling systems as our target. The objectives of this study were: 1) to collect data about the existing waste dry battery recycling processes in Taiwan by a survey of the literature and interviews with experts. 2) to build simulation models according to different recycling situations and determine probable behavior. And 3) to analyze the cost effectiveness of the different recycling schemes.

Real world conditions are relatively complicated and it is necessary to take many factors into consideration when designing a simulation system. Processing parameters and their settings have to be decided according to set of predetermined assumptions. Since the purpose of this research was to analyze the effectiveness of the recycling of dry batteries, the methodology was divided into two steps: 1) Construction of a system model and analysis of the behavior of the recycling scheme through simulation and 2) collection of system output and evaluation of the cost effectiveness of each different recycling scheme.

The rest of this paper is structured as follows. The relevant literature is reviewed in Section 2. The model construction is presented in Section 3. Section 4 illustrates different recycling schemes and Section 5 details the conclusions and limitations.

2. Literature review

An average of eight disposable alkaline batteries is consumed per person per year in the United States according to the US Environmental Protection Agency. This presents an estimated 2.44 billion batteries used and disposed of per year, and the most recent estimate is three billion batteries are purchased in the United States (Krekeler et al., 2012). These spent batteries are of significant environmental concern globally and are major components of the overall hazardous material waste stream and a major contributor to heavy metals in landfills.

To reduce the impact of spent batteries on the earth, the DIRECTIVE 2006/66/EC on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC was enforced in European Union in 2006 to regulate the usage and recycling of batteries. Germany formulated a law in 1998 regarding the collection and disposal of used batteries and accumulators. The battery producers and importers can join the united collect system “GRS batterien” or build its own collect system. This system reveals the Extended Producer Responsibility (EPR) spirit. Producers and importers bear the responsibility of waste dry battery recycling and disposal. An organization like “GRS batterien” was established in Netherlands in 1997. Battery producers and importers composed a united battery collect system, named Stibat. The EPR spirit was revealed in such system. Nowadays, most of battery producers and importers in Netherlands are the member of Stibat (Chen et al., 2010).

The current status of the recycling process has been reviewed in several studies, and it is important that solid recycling policy should be implemented during recycling of spent battery and its materials. However, studies on spent battery recycling are mostly focused on hydrometallurgical chemistry, mainly with the aim of recovering valuable metals from the cathode. From the administrative point of view, a reasonable and feasible recycling policy might increase the effectiveness of recovering valuable metals or reduce harmful materials.

Bertuol et al. (2006) conducted a two-stage investigation of battery recycling. The results demonstrated that recycling is viable due to the relatively large amounts of metal in the batteries. It also demonstrated that magnetic separation is a very efficient process for the recovery of nickel alloys. Zand and Abduli (2008) investigated the current situation of waste household batteries and policies in Iran where increasing technological development after 2001 has resulted in the demand for household batteries growing rapidly. Based on the available data, more than 9800 metric tons of household batteries were imported into Iran in the last decade, with the market value of about US$ 42.6 million. At present, there is no program available in Iran regarding the collection, separation, recycling or safe disposal of used batteries. Therefore, almost all of the spent household are discarded with municipal solid waste and sent to domestic waste landfills. Appropriate policies to meet the safe disposal of household batteries in Iran are also discussed in the investigation.

Krekeler et al. (2012) conducted a study to determine the level of brand diversity, to provide estimates of the size of the waste stream, and the quantities collected for recycling and delivery as landfill. The results indicated that the authority spends $10,000 to collect batteries each year and the estimated cost for collecting all the batteries in the area would actually equal an additional $144,000 to $186,000 per year, which translates into an annual per capita cost of approximately $0.39–0.51 per resident. These results would be useful for the development of a recycling program specific to the environmental policies of the United States. Kannan et al. (2009) proposed a multi-criteria group decision making model in a fuzzy environment to guide the selection process of a best third-party reverse logistics provider. The interactions between criteria were also analyzed before arriving at a decision for selection from amongst 15 alternatives. The analysis was conducted through Interpretive Structural Modeling using fuzzy technique to ascertain the order of preference by similarity to an ideal solution. The effectiveness of the model was illustrated using a case study on the battery manufacturing industry in India.

The abovementioned studies reveal that proper battery recycling policy and regulations are of importance and related researches are conducted globally. Studies on electronic and electrical equipment waste (WEEE) handling are also critical in discussing spent battery recycling policy. Manomaivibool and Vassanadumrongdee (2012) assessed the potential and the limitations of a proposed scheme in Thailand which would have local government buy back targeted WEEE from households at designated locations. Their results showed details of the disposal, and future preferences for this, with reference to ten particular WEEE items: TVs, digital cameras, portable media players, desktop printers, mobile phones, personal computers, refrigerators, air conditioners, fluorescent lamps, and dry-cell batteries, prioritized under the Thai WEEE Strategy.

Extended Producer Responsibility is defined by Thomas Lindhqvist (2000) as follows: “An environmental protection