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Short communication

Brazilian policy on battery disposal and its practical effects on battery recycling

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Abstract

The disposal of batteries is a problem that has grown in the last few years, due to the increase in the use of portable devices. Batteries may contain toxic metals such as cadmium, mercury and lead, so their disposal must be controlled. Brazil was the first country in Latin America to regulate the disposal and treatment of batteries. Limits were established on the concentration of heavy metals within batteries, so that they could be disposed along with domestic waste. Since batteries are products used broadly, it is very difficult to control their disposal. In order to have an efficient collection, the population must be engaged, and that can only happen if they are informed about the laws and regulations regarding the subject, as well as the importance of disposing of batteries with higher concentrations of heavy metals or toxic substances separately from domestic garbage. Around the world, there are some long-established recycling processes for batteries. In Brazil, automotive (lead–acid) batteries have been recycled for several years, whereas the recycling of other types of batteries is just starting. This work does an analysis of the Brazilian law for battery recycling and presents some suggestions and examples of the initiatives of other countries, in order to manage of this kind of dangerous waste.

Keywords: Battery recycling; Battery collection; Battery disposal

1. Introduction

In the last decades, there has been a significant increase in the quantity of batteries disposed of as domestic waste. This fact and the possibility of environmental impact due to the improper disposal of batteries have caused several countries to establish regulations about the disposal of such products motivate their recycling. Brazil was the first country in Latin America to regulate the disposal of batteries. The present work contains a summary of such regulation since 1999. It also compares other countries experiences and offers a general view of the consequences of such regulation on the recycling of batteries in Brazil. Furthermore, it presents some suggestions and initiatives, which may help in the management of this type of municipal solid waste.

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2. Brazilian policy on batteries disposal

In 30 June 1999, the fabrication and disposal of batteries was regulated in Brazil by Brazilian Government's Organization named Conselho Nacional de Meio Ambiente (CONAMA) which is the Brazilian Environmental Council. This was done through CONAMA's Resolution number 257/99. Following, there are transcripts of parts of this Resolution.

> Article 1: After the end of their life, batteries containing lead, cadmium, mercury and its components, shall be delivered by end users to the establishments from where they were purchased, or to the technical assistance network established by the respective manufacturer, to be forwarded to such manufactures or to the importers, which will adopt, directly of through third parties, the procedures of reutilization, recycling, treatment and a correct environmental final disposal.

> Article 5: Beginning from 1 January 2000, the fabrication, importation or commercialization of batteries must

respect the following limits:

- Up to 0.025% in mercury weight, for zinc–manganese and alkaline–manganese batteries;
- Up to 0.025% in cadmium weight, for zinc–manganese and alkaline–manganese batteries;
- Up to 0.400% in lead weight, for zinc–manganese and alkaline–manganese batteries;
- Up to 25 mg of mercury, for button cells.

Article 6: Beginning from 1 January 2001 (. . .):

- Up to 0.010% in mercury weight, for zinc–manganese and alkaline–manganese batteries;
- Up to 0.015% in cadmium weight, for zinc–manganese and alkaline–manganese batteries;
- Up to 0.200% in lead weight, for zinc–manganese and alkaline–manganese batteries.

The Resolution establishes deadlines in which the manufacturers and importers shall implement systems for the collection, transportation, storing, reutilization, recycling, treatment and final disposal of batteries. Batteries which meet the limits or specifications mentioned above may be disposed of by end users together with domestic waste.

The Resolution appears to be very conservative, since the majority of the limits are within those already followed by batteries manufacturers for some years. Especially NiCd and acid–lead batteries are subject to greater control by the industry.

It must be stressed that the environmental consequences of heavy metals are greatly dependent on the conditions in which they are present in the product. So, for example, when Resolution 257/99 establishes a limit of 250 ppm (0.025%) of mercury in the batteries it does not take in consideration that in most batteries the substance is in a soluble condition and this would classify them as dangerous waste if one uses the same classification process used for industrial waste.

NiCd batteries are not within the limits established by the Regulation, since they contain around 17% of Cd [1,2]. Consequently, their collection and destination are regulated by CONAMA's Resolution 257/99. Recycling NiCd batteries is one of the alternatives offered by the Resolution for the destination of this type of battery. Environmental Crimes Law number 9.605/98 punishes with 1–4 years in prison, plus fine, for those who are caught disposing of these materials in common garbage, together with domestic waste. Brazil is the only country in South America which already has laws on the subject.

Presently, the firms who sell batteries that need adequate collection and destination already have an organized collecting system and the destination of such batteries depends on each firm. According to Riedler [3], who studied the present situation of batteries in the Municipality of São Paulo, the population's lack of knowledge regarding the pertinent laws and regulations on the subject was the biggest problem detected in the collection and destination system.

3. International situation

Most of the specific legislation on portable batteries was implemented during the decade beginning in 1990. They are generally focused on mercury restriction in alkaline batteries, dry batteries and button batteries, and also of NiCd batteries. Nevertheless, in some countries such as Switzerland, Norway, Sweden and Germany, there is a general requirement for battery collection which consequently is not limited to specific types of batteries [4].

Many types of batteries contain heavy metals and toxic substances in their composition, therefore, they are potentially dangerous. In a landfill, they are the main source of Hg and Cd, which can be washed out by the rain, causing soil and underground water contamination. In 1989, 54% of Cd and 88% of Hg in landfill had such a source. Besides that, other toxic substances such as ammonium chloride and potassium hydroxide are also normally used as the electrolyte [5].

There is a tendency towards the elimination of mercury in dry and in alkaline batteries and a motivation of the use of systems with longer duration, such as rechargeable batteries. There is also a tendency towards the reduction of use of NiCd batteries, although it is a type of battery with an available recycling technology, while the other portable batteries are not totally recyclable.

Specific legislation on batteries, applicable in all States in the US, originated with the Mercury-Containing and Rechargeable Battery Management Act, passed in 1996 [6].

European Community legislation was passed in 1991(91/157/EEC—Batteries and Accumulators Directive). The objectives of this Directive are to limit the concentration of mercury, cadmium and lead in the batteries, to standardize the identification of recyclable batteries and to develop recycling programs [4]. Besides that, the European Directive has also the objective of establishing progressive goals such as: up to 2008, develop a collecting system so that 75% of portable batteries and 95% of industrial batteries are collected; up to 2009, all Cd must be eliminated and recycling processes shall recuperate 55% of the materials within the batteries. The tendency is to have all batteries collected in all European countries, especially NiCd batteries. The European Association of Batteries Manufacturers agreed in limiting the quantity of Hg in batteries to 5 ppm and to collect all types of batteries in 2003 [4].

Austrian legislation is more restrictive than the European Community's Directive, since it requires the collection of all types of batteries. In this case, the responsibility for the collection and destination relies on the manufacturers and importers. The Danish Environmental Protection Agency's plan is to collect at least 75% of the batteries from 2002 on. In Germany, since 1998, with the Germany's Batteries Ordinance, the responsibility for the collection and destination also relies on the manufacturers and importers. Consumers must turn back any and all types of batteries of whatever origin to a proper collecting system, in which all manufacturers participate. It is estimated that 900 million used household batteries will be turned back annually, representing a total weight of approximately 30,000 metric tonnes [4].

There are few industries in Europe capable of recycling batteries. Special mention should be made to the Accurec Deutschland, in Mühlheim, in Germany, which uses the TERA process and is subsidized the German Environmental Ministry. There are also restrictions to the use of toxic metals in batteries, and the request of specific identification on batteries containing such metals.

Taiwan's Environmental Protection Agency establishes a reduction of taxes related to the reduction of the quantity of toxic metals, in order to stimulate the reduction of such elements [4].

4. Recycling of batteries

As political pressures and new environmental legislation regulating batteries' disposal occurred in several countries, processes were developed for the recycling of such products.

In Europe, in 1999, about 76% of household NiCd batteries were still being disposed in landfills or incinerated [7]. A similar situation occurred in the US: the US Environmental Protection Agency estimates that, in 1999, although NiCd batteries represented only 0.1% of urban waste in weight, they were the main source of cadmium in incinerators. It was estimated that about 75% of cadmium found in urban waste incinerators came from NiCd batteries [8].

4.1. Collection

When discussing battery recycling, collection is as a great problem, since it depends not only on the population's cooperation, but on the cooperation of industries, distributors and the government. A good example when lack of cooperation occurs was a voluntary NiCd batteries recycling program initiated in Sweden in 1993, which had the objective of recycling 90% of NiCd batteries by the summer of 1995. This program failed, reaching only 35% of the batteries [8].

Collection is a very complex aspect of recycling, since associated costs can turn the operation unfeasible, even though the responsibility relies on the public sector.

Specific legislation, based on the polluter–payer principle, was established in some countries, for this type of problem. This means that the manufacturer or the importer of the batteries is also responsible for its destination, after it is used by the consumer.

Brazil does not have such legislation yet, but, in certain sectors, there are some very interesting initiatives which deserve analysis, like the ones regarding aluminum cans, fluorescent lamps and car batteries.

Aluminum is a good example of private initiative's efforts towards recycling of materials used by the population. Presently, Brazilian rate of aluminum can recycling is the highest in the world [9]. Besides, aluminum can recycling industry generates thousands of jobs in the whole country, so the collection of the aluminum cans turned into an alternative source of income for thousands of poor families in Brazil.

Fluorescent lamps contain mercury vapor and when they are broken they liberate mercury into the environment. In Brazil, there is a Company which receives this type of lamp, reclaims the mercury back in a safe process and reintroduces it into the market, thereby avoiding soil contamination. In this case, recycling is promoted by the firms which send the used lamps in special boxes to the Company for the recycling process.

As in the case of aluminum, lead–acid batteries are recycled by specialized companies. There are two ways for collecting such batteries. The first way is the return of the old battery by the end-consumer, when buying and installing a new battery. In cases where the end-consumer purchases a new battery to store it and install it in the car later, in order to collect the old batteries the companies use vehicles with loudspeakers, which circulate around as fruit and vegetables vendors do, announcing the collection of such batteries.

In the US, lead–acid battery collection is motivated by charging a US$ 5.00–10.00 deposit when the end-consumer does not return the used battery. This system caused an increase in the recycling of this type of battery from 95 to 99% in 1998 [8].

In the Brazilian case, the above mentioned collection examples require no government initiatives or obligation. For the three residues, three different strategies were found, according to the population's and product's profile. In the aluminum and lead cases, economic factors are the main aspects in the collecting process, even though the methods for the acquisition of such residues are quite different.

As for the aluminum cans, during a certain period of time, there was an efficient campaign through a major publicity effort, sponsored by can manufacturers, in order to enhance population's participation and conscience regarding the aspects involved. On that occasion, manufacturers were not recycling the cans, but they wanted to keep a good image of their product. As for lead batteries, the strategy was to establish sites for battery exchanges, where the old batteries were collected and the new ones sold.

The case regarding fluorescent lamps is very interesting, since the cost of the segregation is totally covered by firms or entities with an effective environmental concern.

For some residues, however, manufacturers are not interested in contributing to a proper environmental solution to the problem. In such cases, legislation will be passed in order to enforce environmental protection. Thus, pertinent public authorities have the responsibility for passing laws and regulations to motivate the industrial sector and to make them responsible for the development of adequate solid waste management, even if the residues involved are classified as urban waste, and especially if they contain toxic substances or elements which might cause damage to human health and to the environment.

In spite of several countries having specific legislation on the destination of batteries, often the collection is inefficient. In Europe, in 1995, only about 5% of household NiCd batteries were recycled, while industrially used NiCd batteries presented a much higher recycling of rate, approximately 48% [10].

Each country has a different collection strategy. Germany, for example, has tested a collection strategy of motivating the consumer to separate the batteries and return them. This strategy had a very poor efficiency, since approximately 50% of the batteries were not NiCd. A better result was reached by motivating consumers to return used batteries to the shops, which sorted the batteries and forwarded them for recycling [10].

In Brazil, a collecting system for rechargeable batteries is just starting and it is still difficult to appraise its efficiency. Besides that, no NiCd batteries importer recycles in the country. Presently, all rechargeable batteries are supposed to be collected by the outlets which sold them.

5. Recycling

There are several established systems for battery recycling [11–13]. Such processes are in use mainly in developed countries, such as the US, some European countries and Japan. Brazilian legislation does not oblige the recycling of dry and alkaline batteries, since their concentration of heavy metals is within established limits.

The most important types of household used rechargeable batteries are Pb–acid, NiCd, NiMH, and Li ion. Pb–acid batteries were the first ones to be recycled and the population for a long period of time has extensively used it. Their recycling process is established and they are recycled in several countries around the world. Countries have also developed collection programs for this type of battery. Thus, although containing Pb, which is a toxic metal, it does not represent a great environmental risk, since the recycling rate is high and they are not disposed of in landfills.

The use of NiCd by the population became more significant in the second half of the 20th century, especially since the 1980s, as a result of the great increase in the use of eletronic equipment. At such time, the disposal of NiCd household used batteries in landfills began to be questioned, although it was not yet considered a problem. The estimated quantities of disposal of such batteries indicated that it would become a problem in a short period of time. A study which lasted for 100 days showed that mercury batteries suffered corrosion in landfills and liberated their contents. Dry batteries also showed evidence of corrosion. During the 100 days of the study, the NiCd batteries were perforated, but their contents had not been liberated. It was estimated that lets the NiCd batteries contents would also be transferred to the leachate of the landfill [14].

The NiMH and the lithium ion batteries do not contain heavy metals restricted by law, but there is an international tendency towards the recycling of such type of batteries. The use of those batteries have increased, substituting the use of NiCd batteries.

Unfortunately, it is not always easy to distinguish on a glance one type of battery from the others, and thus they are usually collected altogether. Literature emphasizes the importance of contamination in the joint recycling of mixed types of batteries. Generally, recycling processes used for dry and alkaline batteries do not accept contamination with NiCd batteries, and vice versa.

Presently, mixing NiCd batteries with dry and alkaline batteries should be avoided in pyrometallurgical processes that recycle batteries, since in the case of contamination, the zinc recovered would be contaminated by cadmium. The same observation must be applied for the NiCd batteries recycling processes, in which cadmium recovered would be contaminated by zinc.

Another volatile metal which can contaminate products in pyrometallurgical processes is mercury, which does not only contaminate the recovered metal but is also a toxic metal by itself.

NiCd batteries' recycling processes can also handle NiMH batteries [15], but the process is restricted to the recuperation of the Ni contained in the batteries. Other elements, such as Rare Earths, are not recovered. Hydrometallurgical processes that are still development must be developed in order to recover Rare Earths.

Lithium ion batteries are another type of batteries which have an extensive domestic use, but there is not yet a recycling process developed for this type of battery. In Lithium ion batteries, cobalt is the most important metal to be recovered. Nevertheless, research for the development of new materials for electrodes to be used in the lithium ion system have a tendency to attempt to substitute cobalt for a cheaper metal, in order to reduce final cost since it is higher than that of NiCd and NiMH batteries.

Processes are being developed in order to separate batteries according to their composition. One of these processes uses X-rays to analyze and separate the batteries [16–18].

6. Discussion

Several recycling processes for NiCd batteries are presently operating. However, a collection system for this type of battery is not yet as well established as the collection for Pb–acid batteries. In the US, the firm Rechargeable Battery Recycling Corporation (RBRC) collects NiCd batteries and sends them to be recycled through the Inmetco process. Since 2000, RBRC is also collecting other types of batteries for recycling. Besides the batteries sent in by RBRC, Inmetco also receives batteries by mail [19].

In Europe, the European Portable Battery Association (EPBA) not only collects batteries but also motivates its collection and separation processes through publicity and conferences.

In Brazil, there are no associations or firms responsible for the collection of NiCd batteries which are also active in motivating and informing the general public. The collection is usually an importers' initiative and it is done in a dispersive form. There are no public sector entities, nor associations or firms charged for the collection of such residues. The population is not familiar with the Resolution which regulates batteries disposal and determines the devolution of some types of batteries. The general public is not aware whether the batteries they possess are among the types of batteries that can be disposed along with domestic waste [3].

CONAMA's Resolution 257, which regulates the disposal of batteries, does not establish specific goals for the collection of the types of batteries that must be collected, as it occurs in Europe. This causes less efficiency in the collection effort.

Importers of NiCd batteries generally receive used batteries if turned in by end-consumers and only if the battery is one of the same brand they imported. It is up to the citizens to find out how to turn in used batteries and there are no campaigns informing and motivating people to forward used batteries to the technical assistance of the battery's brand.

Cellular phone batteries are the ones in most evidence, since all who own one know that the battery must be periodically recharged up to the moment when it has to be changed for a new one. But there are other electronic products that may contain NiCd batteries, such as toys, emergency lights, wireless tools, wireless phones, video cameras, notebooks and many other equipment that use rechargeable batteries. The majority of the people are not aware which type of battery is inside the equipment or even if there are any batteries installed in them at all.

NiMH and lithium ion batteries are replacing NiCd batteries for household use. As already stated, these types of batteries, although less harmful to the environment, have a higher cost for the consumers and do not yet have a established recycling process as NiCd batteries do.

The present battery management model adopted in Brazil has contradictions and flaws, as discussed above. But one can not deny CONAMA's merit in the initiative of passing a Regulation which is the first one in Latin America to regulate batteries.

But Brazilian legislation did not promote the recycling of any type of battery, not even those with more restrictions, such as Pb–acid and NiCd batteries, as opposed to what happened in other countries, especially in the US and certain European countries, which have specific legislation recycling on batteries. One of the main consequences must be the disappearance of NiCd cellular phone batteries from the market; however, such batteries still have other uses.

Cd banning from batteries, as proposed in some European Directives, is apparently more and more distant from becoming feasible [20]. Besides, NiCd batteries have established recycling processes. Even though they have a grater polluting potential than NiMH and Lithium ion batteries, NiCd batteries have a completed Life Cycle, and therefore, could be considered more sustainable that the other types.

There is also a need to adopt a more sustainable development for the energy sector. In this case, NiCd industrial batteries still are the one of the main alternatives, since more recent systems, such as the ones regarding NiMH and lithium ion batteries, do not have the same operating characteristics.

Thus, one of the alternatives towards a sustainable development could be the preparation of specific recycling goals, associated with a management structure and the promotion of the collection and recycling of all types of batteries, with the costs absorbed by the products prices.

Such actions would improve not only the implementation of environmental education, collection and recycling systems, but also the development of new batteries, easier to be recycled and containing less toxic substances.

References

[1] F. Von Sturm, Secondary batteries–nickel-cadmium battery, in: J.O.'M. Bockris, Comprehensive Treatise of Electrochemistry, vol. 3, Plenum Press, New York, 1981, pp. 385–405.

[2] P.A. Adams, C.K. Amos, Batteries, in: H.F. Lord, The McGraw-Hill Recycling Handbook, McGraw−Hill, New York, 1993, pp. 19.1–19.32.

[3] N.M.V.L. Reidler, Resíduos Gerados por Pilhas e Baterias Usadas: Uma Avaliação da Situação Brasileira 1999–2001, Master Dissertation—Faculdade de Saúde Pública, University of São Paulo, São Paulo, 2002, 183 pp.

[4] United States Environmental Protection Agency (USEPA), Product Stewardship—International Initiatives for Batteries, online http://www.epa.gov/epaoswer/non-hw/reduce/epr/products/bintern.html, 3 August 2002.

[5] B. Fishbein, Industry Program to Collect Nickel–Cadmium (Ni–Cd) Batteries, online http://www.informinc.org/battery.html, 3 August 2002.

[6] United States Environmental Protection Agency (USEPA), Implementation of the Mercury-Containing and Rechargeable Battery Management Act, online: http://www.epa.gov/epaoswer/hazwaste/recycle/battery.txt, August 2002.

[7] A. Cox, D.J. Fray. Recycling of cadmium from domestic, sealed NiCd battery waste by use of chlorination, Trans. Instn. Min. Metall (Sect. C: Mineral Process. Extr. Metall) set./dez. 108 (1999) C153–C158.

[8] U. Valiante, Batteries not included, hazardous materials management, January 1999, online http://www.hazmatmag.com, 30 November 2001.

[9] Associação Brasileira de Alumínio, ABAL, Números da Indústria Brasileira de Alumímio—Reciclagem, online http://www.abal.org.br/numeros/index.cfm?frame=numeros_reciclagem, 20 September 2001.

[10] J. David, Nickel-cadmium battery recycling evolution in Europe, J. Power Sources 57 (1995) 71–73.

[11] A.M. Bernardes, D.C.R. Espinosa, J.A.S. Tenorio, Collection And recycling of portable batteries: a worldwide overview compared to the Brazilian situation, J. Power Sources 124 (2) (2003) 586–592.

[12] A.M. Bernardes, D.C.R. Espinosa, J.A.S. Tenorio, Recycling of batteries: a review of current processes and technologies, J. Power Sources 130 (1–2) (2004) 291–298.

[13] C.C.B.M. De Souza, D.C. De Oliveira, J.A.S. Tenorio, Characterization of used alkaline batteries powder and analysis of zinc recovery by acid leaching, J. Power Sources 103 (1) (2001) 120–126.

[14] C. Stevens, J. Wright, Disposal of spent batteries, Chem. Ind. 5 (1980) 527–529.

[15] J.A.S. Tenorio, D.C.R. Espinosa, Recovery of Ni-based alloys from spent NiMH batteries, J. Power Sources 108 (1–2) (2002) 70–73.
[16] S. Rausch, Sorting of spent batteries by a fast X-ray technique in the Sorbarec-process, in: Proceedings of the Fourth International Battery Recycling Congress, Hamburg, Germany, 1–3 July 1998.
[17] H.P. Satter, See the label—know the type: a new sorting technique for spent batteries, in: Proceedings of the Fourth International Battery Recycling Congress, Hamburg, Germany, 1–3 July 1998.
[18] N. Watson, Post consumer battery sorting: a review of the high speed sorting process in the Netherlands, in: Proceedings of the Fifth International Battery Recycling Congress, Deauville, France, 27–29 September 1999.
[19] R. Lankey, Materials management and recycling for nickel-cadmium batteries, Ph.D. Thesis, Department of Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, 1998, 212 pp.
[20] Letsrecycle.com battery recycling, online http://www.letsrecycle.com/legislation/batteries.htm, 11 October 2002.