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The battery recycling loop: a European perspective

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Abstract

Restricting the loss of lead into the environment is essential and European legislation has reacted by requiring the recycling of lead/acid batteries. With the forecast of strong growth in the battery market over the next decade, secondary lead output will need to increase substantially to supply this demand. Battery recycling rates are vulnerable, however, to low lead prices and restrictive legislation. Effective recycling schemes are required to ensure maximum recovery and several are successfully in operation. Environmentally sound technology exists to recycle the lead and polypropylene components of batteries. A full range of lead and lead alloys are available to the battery industry from secondary material and now challenge primary products in most battery applications. It is important to optimize recycling efficiency and minimize environmental damage.

Keywords: Lead/acid batteries; Recycling; Environment; Battery industry; Lead industry; Europe

1. The responsibility to recycle

There are few people who would argue against the need to take action to prevent loss of lead into the environment. Lead is an established toxin and, indeed, has a disproportionately poor image in the public perception, primarily through campaigns against the use of lead in gasoline and paints.

European governments have responded to these pressures by imposing and proposing an array of new and future legislation. Principal amongst these is *EC Directive 91/157/EEC* [1], which requires the collection and controlled disposal of lead/acid batteries. The implication of controlled disposal for lead/acid batteries is to recycle them.

Fortunately, operations and associated infrastructure for recycling lead are well established. Although lead has been recycled to some extent for centuries, modern technology has allowed the consequential environmental impact of secondary smelting and refining to be minimized. In addition, the proportion of lead end-uses that are currently recycleable is over 75% and is expected to rise to 85% by 2005 [2], largely through growth in the battery market. Of the remaining non-recyclable applications, an increasing fraction poses no environmental risk since the lead is bound in an inert matrix, e.g. leaded glass used for television tubes and visual display units.

Future legislation directed towards producer responsibility will place even more stringent restrictions on lead manufacturing and use. Indeed, manufacturers may even be compelled to take back used products. With this inexorable legislative march towards ever tighter controls on lead in the environment, it is essential that the industry establishes effective and responsible recycling programmes before future regulations make this impossible. Only through such actions will the industry credibly be able to promote lead as an environmental-friendly metal, with the significant majority of its modern applications being both recycleable and bringing direct environmental benefits [3].

2. The need to recycle

Over the last ten years, the total lead production in the western world has increased by 4% [2]. It is forecast to

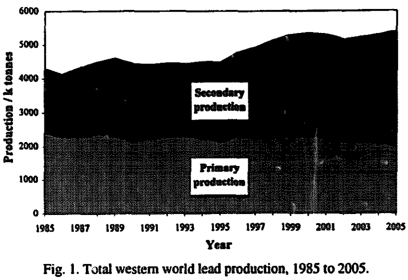

Fig. 1. Total western world lead production, 1985 to 2005.

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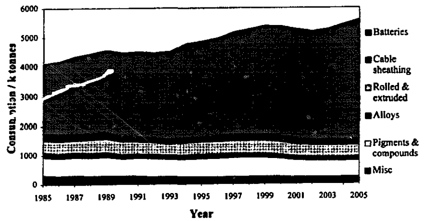

Fig. 2. Western world lead consumption by end-use, 1985 to 2005.

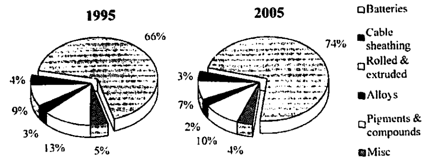

Fig. 3. Western world lead consumption by end-use, 1995 and 2005.

increase by a further 20% in the coming decade (Fig. 1). Over this period, however, the level of primary lead production will remain almost static; all the growth will be generated from secondary output. Recycled lead now represents just over half of all lead produced, and is predicted to increase to 62% of the total by the year 2005. This corresponds to a growth of over 40% in secondary lead over the next ten years.

From examination of lead end-uses in the period 1985 to 2005 (Fig. 2), and specifically the years 1995 and 2005 (Fig. 3), it is clear that the only continuing expansion will occur in the battery sector. Thus, efficient battery-recycling systems will be required to return sufficient lead to the secondary production circuit to sustain this growth. Widespread utilization of electric vehicles in the future will only intensify these needs.

3. Battery recycling rates and collection schemes

The determination of battery recycling rates is recognized as a complicated and inexact science. Calculations must take into account the various battery types with their corresponding average service life and weight, production scraps, imports and exports, stock variations, the number of vehicles broken, collection and stockpiling delays, and the mass of batteries recycled at the smelters. Various models exist for this estimation, each with a different method of calculation. Perhaps the best known are those of the Battery Council International (BCI) and the Commodities Research Unit (CRU). Although the estimates derived from various models may be useful, it is rather more important to use a consistent technique and analyse the trends in recycling rates. Examples of these are shown in Table 1 [4,5]. Whilst there are national variations in the models used, the trends are clearly towards increased recycling rates from already high levels.

Motive power and stationary batteries, by the nature of their volume and manufacturer supply and return basis, tend to have recovery rates approaching 100%. Nevertheless, it is the starting, lighting and ignition (SLI) batteries, with their 78% share of the sector, that dictate overall battery recycling rates.

In some cases, notably the UK, the recycling rate has declined in recent years. The major cause has been the low market price for lead that provides a disincentive to collection, exacerbated by the increased regulatory pressures on traditional collection routes that have forced many scrap merchants to avoid the handling and storage of lead/acid batteries altogether. Alarmingly, this can extend to a reluctance to remove batteries from scrap vehicles, which has resulted in a significant rise in lead emissions from many steel-making plants. More recently, however, the UK rate has improved again, mainly due to an increase in the lead price and some development of collection schemes.

In Europe, the problem is being addressed in a variety of ways. Within the European Community, *EC Directive 91/157/EEC* requires member states to submit plans to ensure organization of a collection and recovery scheme, as well as any financial measures that are required to promote collection. In addition, consumers should be educated on the dangers of uncontrolled disposal, with batteries suitably labeled to show they can be recycled and must not be disposed of in domestic waste. It is notable that most member states have failed to implement the provisions of the directive by the required date of 18 September 1992.

Table 1
Lead/acid battery recovery rates (%) in various European and other OECD countries

Year	1986	1987	1988	1989	1990	1991	1992	1993
Belgium	77				80			85
France	80			90	90			90
Germany	83				95	>95		95
Italy	83				85			85
Spain	83				85			85
Sweden						>100		
UK	84	86	88		90	93	92	80
Japan	92	93	95	94	92			
USA		89	91	95	98	97		97

During the mid-1980s, the battery recycling rate declined significantly in Sweden. This was due largely to low lead prices that undermined the economics of transporting scrap over long distances to the only secondary smelter in the south of the country. The Swedish response in 1989 was 'Returbatt', the first European recycling scheme in operation, which coordinates battery collection and promotes a public awareness programme. Additionally, all battery retailers are required to accept spent batteries. Revenue from a SKr 35 levy (approximately US $5) charged on all battery sales is used to subsidize unprofitable stages of the collection chain and finance the public education project.

Italy, an EC member, introduced a similar system in 1990, but with significant differences. 'Cobat' is a mandatory non-profit-making consortium with members drawn from lead smelters, scrap collectors, the battery industry and government. The main objectives are coordination of collection and recycling, levies on new battery sales, and appropriate public education. Retailers are not required to accept spent batteries. The consortium gains income from both the levy on new batteries and the purchase of scrap batteries from collectors which are then sold to smelters. To avoid the levy being a source of unearned profit when the scrap battery value is adequate to fund recycling, there is a sliding scale of prices to collectors and smelters dependent on the London Metal Exchange lead price. Any 'Cobat' surpluses are used to fund research and awareness programmes.

To date, both the 'Returbatt' and 'Cobat' systems have proven reasonably successful. Elsewhere in Europe, countries such as Poland and the Czech Republic are preparing schemes based essentially on those in Sweden and Italy [6,7].

The desirability and advantages of a pan-European battery recycling scheme are obvious. Nevertheless, with the continuing inertia of the EC Directive and the impediments of the Basel Convention on cross-border movement of wastes, it will not become a reality in the near future.

4. Recycling technology

Having collected spent batteries and transported them to the recycling plant, modern technology allows efficient recycling of battery components. Plastics are recovered by automated battery breaking through use of systems such as the Engitec Impianti CX or MA Industries plants, the former of which is used at Britannia Refined Metals Ltd. in Northfleet, UK. Besides the environmental justification of separating and reprocessing the plastics, as well as reducing disposal volume by 50%, revenue from recycled polypropylene granules can represent a further 10% added value to the overall process.

4.1. Battery breaking

Incoming scrap to Britannia's battery-breaking plant is stored initially in a covered building with drainage of free acid to storage tanks. Batteries are crushed in a hammer mill after which a vibrating washing screen separates the battery paste for collection in a stirred tank prior to desulfurization. Oversize from the screen is fed to a hydrodynamic classification system that separates the remaining components, viz., metallic grids and top lead, polypropylene, ebonite and separators.

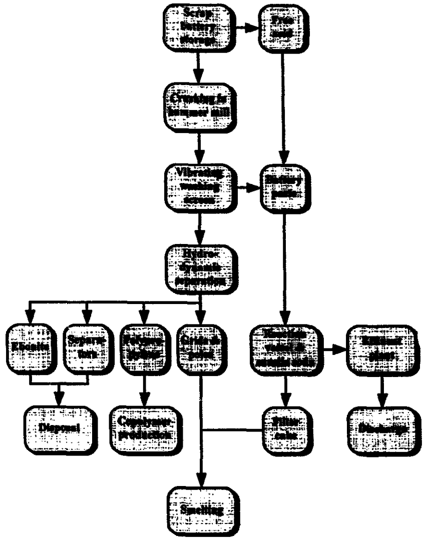

Fig. 4. Process flowsheet of CX plant for battery breaking.

The paste slurry (lead dioxide, lead and lead sulfate) is pumped to reaction vessels with collected battery acid and liquid caustic soda, where the following reactions occur:

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2H_2O \quad (1)$$

$$PbSO_4 + 2NaOH \rightarrow Na_2SO_4 + PbO + H_2O \quad (2)$$

After completion of these reactions, the vessel contents are pumped to a pressure filter. The filtrate is transferred to an effluent plant where it is treated and neutralized before discharge. After washing to remove residual sodium salts, the filter cake is conveyed to storage prior to smelting. The flow sheet for the process is shown in Fig. 4.

4.2. Smelting

Traditionally, lead from battery scrap has been smelted in rotary or blast furnaces, usually to produce antimonial lead bullion and soda slags or mattes. More recently, however, new smelting technologies have been developed. These offer improvements in metallurgical and environmental performance whilst still being competitive in terms of capital and

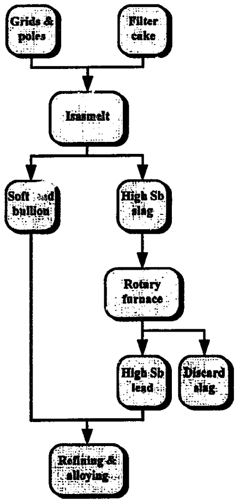

Fig. 5. Flowsheet of Isasmelt lead-smelting process.

operating costs, especially when long-term environmental compliance expenses are considered.

Principal amongst these new technologies is the Isasmelt process, first used for secondary lead smelting in 1991 at Britannia's Northfleet refinery. The process uses the submerged top entry lance developed in Australia by the Commonwealth Scientific and Industrial Research Organization (CSIRO). This lance features internal helical vanes that impart a swirling motion to the air/fuel mixture and enhance the cooling of the lance by the process gas. As a consequence, a protective frozen slag layer is formed on the lance and this allows prolonged submersion in the aggressive liquid slag layer without excessive wear.

The smelting of metallic lead and paste in the Isasmelt process produces a low-antimony, soft lead bullion ($Sb < 0.1$ wt.%) and a high-antimony slag. This is achieved by continually charging 30 t of feed to the furnace and smelting for about 3 h. At the end of this period, soft lead is tapped and a new batch of feed is charged on top of the slag. This process can be repeated around eight times before the slag must be tapped. The high-antimony slag is then treated in a rotary furnace to produce a lead bullion with up to 20 wt.% antimony, together with discard slag. The flow sheet for the smelting process is presented in Fig. 5.

The soft lead bullion from the Isasmelt process requires very little further refining after charging to process kettles with a capacity of 120 t. The bullion is low in antimony, copper and other impurities. Thus, soft refined lead and alloys can be produced easily; antimonial alloys are made separately from the smelting of the high-antimony lead slag.

The combination of the CX plant for paste desulfurization and the Isasmelt process (with minimized off-gases from the intense smelting medium) results in very low sulfur emissions to atmosphere.

5. Secondary products

Production of recycled polypropylene is an expanding feature of the recycling business. The polypropylene chips recovered from the battery-breaking process are washed thoroughly and dried prior to extrusion and granulation as a copolymer. Colouring agent is added at this stage to produce a variety of shades, with typical analyses of 93.5 wt.% propylene and 6.5 wt.% ethylene. The lead content (<0.04 wt.%) is encapsulated in the granules and is virtually non-extractable. The levels of poly(vinyl chloride) (PVC) are also <0.04 wt.%.

The material properties of the recycled copolymer are very close to those of the virgin copolymer that has been used in the battery industry for a number of years. For this reason, the manufacture of new battery cases from recycled polypropylene is now gaining wide acceptance in the battery industry. The copolymer is also used for production of other automotive parts, tool handles, pipe fittings, plant pots, etc., and for more technical applications when combined with talc, carbonate or glass fibre.

The majority of lead products derived from recycled material return to recycleable applications. Besides refined lead (typically at 99.97 or 99.985 wt.% grade), a full range of antimonial and calcium battery alloys can be made. Other alloys produced may be used for radiation shielding, cable sheathing, and lead sheet for construction. These secondary lead alloys are made to quality standards that rival all but the very best primary lead. Indeed, the line of distinction between primary and secondary lead has now blurred to the point where, in many cases, they are essentially interchangeable. Clearly, with the continually increasing technical requirements on secondary lead products, it is essential that they are able to fulfill the highest demands of industry.

6. Recycleability

Before concluding, it is appropriate to mention the recycleability of lead/acid batteries. No responsible battery company should now be producing a battery without first considering its recycleability. The secondary lead industry continues to find that problem materials are being used. The main offenders are ebonite or acrylonitrile/butadiene/styrene (ABS) cases, the latter usually used for flame retardancy, and PVC separators. Whilst very few battery producers still use ebonite in Western Europe, battery scraps in other parts of Europe can still feature a majority of ebonite cases and PVC, or partial-PVC, separators [7]. These materials cannot be recycled practically and, if not dumped to landfill, are processed in smelting furnaces. An after-burner system is required to destroy the volatile organic compounds that are given off. This produces chlorine-containing dust for collection in filters, together with lead-bearing fume. Subsequent processing of these dusts in a rotary furnace produces a leachable chlorine-containing slag that must be sent to a hazardous landfill waste dump. Environmentally, these procedures are plainly unsatisfactory. Financially, future European legislation will further escalate landfill disposal costs.

Problems also exist with the recycleability of lead from batteries. For example, copper from brass inserts, or nickel from plated components, are difficult to remove from lead and require separate processes at the refining stage. This represents a cost to the smelter that will eventually be passed on to the lead purchaser through increases in premia.

Furthermore, a solution is required for components that are contaminated with low levels of lead and that have no economic value, such as polyethylene separators. The development of an efficient levy fund could finance the study of safe treatment and disposal methods for these materials, along with flame-retardant polypropylene to obviate the use of ABS.

7. Conclusions

It is essential to restrict the loss of lead into the environment. European legislation has responded to this need through regulations that require the recycling of lead/acid batteries.

With the strong growth in batteries over the next decade, secondary production volumes will need to increase substantially both to supply this demand for lead and to consume the additional feed from more scrapped batteries.

Recycling rates are generally high but vulnerable to the influences of low lead prices and restrictive legislation. Effective and environmentally responsible recycling schemes are required to ensure maximum recovery of scrap batteries. Successful schemes are operating in Sweden and Italy, but the implementation of systems in other countries is progressing slowly.

Environmentally sound technology exists to recycle components of lead/acid batteries. Polypropylene can be separated and regenerated as copolymer granules for remoulding. This adds value to the recycling loop. Lead and desulfurized paste can be smelted to produce soft lead bullion and high-antimony lead to optimize refining efficiency. A full range of lead and lead alloys is available to the battery industry from secondary material and they now challenge primary products in most battery applications.

Finally, recycleability should be a leading concern to battery producers. Non-recycleable plastic cases and metallic components that require additional refining processes increase disposal volumes, smelting costs and the potential for environmental damage.

With the entire European lead industry under ever-closer public scrutiny, implementation and promotion of an efficient battery-recycling loop will justify the primary importance of secondary lead as the environmental-friendly metal.

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