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Air and Blood Lead Levels in Lead Acid Battery Recycling and Manufacturing Plants in Kenya

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INTRODUCTION

Occupational lead (Pb) exposure causes a variety of serious adverse health effects.1–6 Studies have shown that there are thousands of workers with elevated blood lead (BPb) levels in the developing world.2,3,5 High airborne Pb exposures have been reported in Pb acid battery recycling and manufacturing facilities.1–6 It is estimated that about 6 million tons of Pb is used annually worldwide, of which about 75% goes into the production of Pb acid batteries.2 These batteries are used in automobiles and in solar panels in rural areas of developing countries.2,3

With an increase in the number of automobiles, off-grid power technologies, and requirements for back-up power supplies in Kenya, an annual growth rate of more than 24% is expected in Kenya’s production of Pb acid batteries.7 Like other developing countries, Kenya is transitioning to an industrial economy with minimal attention to controlling occupational health hazards.2,4,5,8–11 In addition, there are limited resources for performing Pb analyses in air and biological media.10 The incidence of Pb poisoning is likely to increase among workers in Pb acid battery recycling and manufacturing plants during the phase of rapid industrialization.4,5 Kenya does not have national workplace standards for permissible airborne Pb exposure and BPb levels. The results obtained from this study establish baseline levels of Pb exposure in the targeted workplaces.

MATERIALS AND METHODS

There were three medium-sized plants that recycled Pb acid batteries and four Pb acid battery manufacturing plants among the companies that were registered and licensed by the Ministry of Labour and Human Resource Development through the Directorate of Occupational Safety and Health Services. However, in addition to these registered companies, there were numerous unlicensed battery reconditioners and small-scale smelters.

Permission was obtained to evaluate occupational exposure in one recycling plant (Plant A) and one manufacturing plant (Plant B), which are situated about 30 km and 7 km, respectively, from Nairobi City center. These plants had the same owners, but their management and operations were independent of each other. Field investigations began in September 2009 and ended in November 2010. Workplace sampling and
observations were made by a team of professionals and trained researchers.

Each plant employed about 100 permanent workers and more than 50 temporary workers and operated with three 8-hr shifts. These workstations were not strictly segregated from each other, and the production area in each plant was a large contiguous air space within which different workstations were located. Workers in a given processing section tended to remain in the same area, such that there was no job rotation.

**Plant A – Lead Acid Battery Recycling**

The facility recovered Pb from used lead acid batteries (ULABs) with an annual production of about 8000 tons of ingots. There were four major workstations: (1) battery breaking, (2) furnace, (3) refining, and (4) casting. Drained ULABs were delivered to the facility, and breaking section workers manually offloaded and stockpiled them outside the plant about 15 m from the entrance to the breaking section. The breaking area consisted of an outdoor shed where the workers manually broke up the ULABs with axes. The crushed materials were a mixture of Pb oxide, Pb sulfate, plastic chippings, and metals such as calcium, nickel, antimony, and arsenic. The plastic chippings were sorted manually from the crushed materials by hand, such as calcium, nickel, antimony, and arsenic. The plastic mixture of Pb oxide, Pb sulfate, plastic chippings, and metals broke up the ULABs with axes. The crushed materials were a mixture of Pb oxide, Pb sulfate, plastic chippings, and metals such as calcium, nickel, antimony, and arsenic. The plastic chippings were sorted manually from the crushed materials by hand, and the same workers. These materials, excluding the plastics, were transported to the furnace section for the reduction process.

In the furnace section, workers charged these materials together with a reducing agent (coal) into a furnace, at a temperature of 1000 to 1200° C, to separate Pb from the mixture. The molten Pb was then drained through a tap hole into kettles and passed on to the refining section. Workers in that section remelted the Pb, added chemicals, and removed the slag residue. The furnace and refining operations were carried out in the same area. Slag residue was dumped on the ground inside the plant near the refining section and subsequently transported to a municipal solid waste site. In the casting section, refined molten Pb was poured into molds and cast into Pb ingots. Office workers in this facility included accountants and clerks who worked in a space physically segregated from the processing areas.

**Plant B – Lead Acid Battery Manufacturing**

The plant produced approximately 750,000 batteries per year. There were three major processing areas: (1) grid casting, (2) pasting, and (3) stacking/assembling. To make battery grids, workers charged Pb ingots into a melting pot, from which the molten Pb flowed into casts that formed the grids. In the pasting process, dry ingredients consisting mainly of Pb oxide were manually added to a mixing pot. Workers prepared positive pastes from a mixture of Pb oxide powder, water, and sulfuric acid, and prepared negative pastes from the same components, in slightly different proportions with the addition of an expander. The pasting machines forced these pastes into the interface of the casted grids to make plates. The plates were allowed to dry and cure and were polished by the pasting section workers. These plates were then moved to the stacking/assembling section, where they were manually cut apart into doublet plates and stacked with alternating positive and negative blocks with insulators between them. The Pb tabs on each positive and negative plate were welded and placed in the battery cases before fitting the top covers. The office workers in this facility also included accountants and clerks who worked in a space physically segregated from the processing areas.

**Blood Lead Sampling and Analysis**

Blood samples were taken from workers in areas where air samples were also collected. In Plant A, the percentage of the workers who provided blood samples were 83% in the furnace, casting, and refining sections, and 50% in the office area. In Plant B, the percentage of workers who provided blood samples were 78% in grid casting, 75% in pasting, 65% in stacking/assembling, and 62% in the office area. For each subject, a medical officer drew 4 mL of blood into a disposable syringe; the blood was transferred to a labeled Pb-free heparinized vacutainer tube. Previous studies established that the vacutainer needles and heparinized tubes that were used did not add measurable Pb to the blood samples.(12) Blood samples were stored at –20°C prior to analysis.(12-14)

A Buck Model 210 VG5 graphite furnace atomic absorption spectrophotometer (GFAAS; Buck Scientific, Inc., Norwalk, Conn.) with a hollow cathode lead lamp and a deuterium arc background corrector was used to analyze Pb in blood and standard solutions. Lead standard solutions in 0.01 M nitric acid were prepared from a commercial stock standard of 1000 µg Pb/mL and were used to generate a standard calibration curve. The blood samples were thawed and diluted 10-fold with 0.01 % vol/vol Triton X-100.(14) Ten microliters (10 µL) of the diluted blood samples and an equal volume of a matrix modifier mixture (0.6 % ammonium dihydrogen phosphate, 0.15% wt/vol magnesium nitrate in 0.01 M nitric acid) were automatically injected sequentially into a pyrolytically coated graphite tube under optimized conditions.(14) The Pb concentrations in blood samples were obtained directly from the standard calibration graph after correction of the absorbance of the signal from appropriate reagent blanks.

**Air Lead Sampling and Analysis**

In both plants, introducing the use of personal air sampling pumps was met with resistance by both workers and management. Because it would have required a substantial amount of time to make workers and management comfortable with the pumps, and since our sampling was intended as a preliminary study, area sampling was used instead. Area samples were
TABLE I. Airborne and Blood Lead Levels in Lead Acid Battery Recycling Plant A

<table>
<thead>
<tr>
<th>Sampling Locations</th>
<th>Airborne Lead Levels (µg/m³)</th>
<th>Blood Lead Levels (µg/dL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range (No. of Values)</td>
</tr>
<tr>
<td>Breaking</td>
<td>420 ± 127</td>
<td>275–570 (5)</td>
</tr>
<tr>
<td>Furnace</td>
<td>447 ± 154</td>
<td>320–620 (5)</td>
</tr>
<tr>
<td>Casting</td>
<td>430 ± 101</td>
<td>295–530 (5)</td>
</tr>
<tr>
<td>Refining</td>
<td>405 ± 137</td>
<td>215–600 (5)</td>
</tr>
<tr>
<td>All production</td>
<td>427 ± 124</td>
<td>215–620 (15)</td>
</tr>
<tr>
<td>Canteen</td>
<td>123 ± 35.6</td>
<td>81.0–134 (5)</td>
</tr>
<tr>
<td>Office</td>
<td>59.2 ± 22.7</td>
<td>30.0–81.0 (5)</td>
</tr>
</tbody>
</table>

Note: NS = not sampled.

TABLE II. Airborne and Blood Lead Levels in Lead Acid Battery Manufacturing Plant B

<table>
<thead>
<tr>
<th>Sampling Locations</th>
<th>Airborne Lead Levels (µg/m³)</th>
<th>Blood Lead Level (µg/dL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Range (No. of Values)</td>
</tr>
<tr>
<td>Pasting</td>
<td>378 ± 109</td>
<td>201–470 (5)</td>
</tr>
<tr>
<td>Stacking/assembling</td>
<td>322 ± 105</td>
<td>190–480 (5)</td>
</tr>
<tr>
<td>Grid casting</td>
<td>348 ± 125</td>
<td>215–510 (5)</td>
</tr>
<tr>
<td>All production</td>
<td>349 ± 107</td>
<td>190–510 (15)</td>
</tr>
<tr>
<td>Canteen</td>
<td>66.2 ± 13.3</td>
<td>46.0–79.0 (5)</td>
</tr>
<tr>
<td>Office</td>
<td>55.2 ± 33.2</td>
<td>13.0–75.0 (5)</td>
</tr>
</tbody>
</table>

Note: NS = not sampled.
In the furnace area of Plant A wore elastomeric half-mask respirators with cartridges containing activated charcoal and a particulate filter layer. There was no particle size rating on the filtering-facepiece respirators, only one size of each type of respirator was provided, and workers were not fit tested for the respirators. Many workers were observed not wearing their respirators consistently during their work shift. Although respirator use likely reduced the average inhaled Pb concentrations below the average ambient Pb concentrations, it is certain that inhalation exposure was substantial despite respirator use.

In general, the visual observations made in the two plants were that the engineering controls, work practices, and personal hygiene measures, along with respiratory protection use, were inadequate to minimize Pb exposures. In Plant A, there were two sprinkler systems on the walls of the furnace area that continuously sprayed water mist to reduce airborne Pb fumes and dust, but their number and location in comparison with the area coverage were inadequate. The furnace was equipped with a canopy-type receptor hood above the charging portal. However, the hood’s exhaust system appeared inefficient, as visible smoke was evident in the area surrounding the hood. The air supply in all processing sections was provided by open doors. The air drafts may have dispersed Pb-containing particles to adjacent workstations as well as to the office and canteen areas. There was no local exhaust ventilation observed other than at the furnace area of Plant A.

The battery-breaking section of Plant A was an open shed immediately bordered by trees on one side, and these trees limited the degree of natural dilution ventilation within the shed. In addition to Pb dust released due to breaking of the batteries with axes, broken materials were manually sorted and loaded into containers moved by forklifts to the furnace area, and workers were observed dry sweeping pavement littered with broken materials. The combination of activities that generated Pb dust, and the limited natural ventilation in the shed, may have led to the high concentrations of Pb measured outdoors. The Pb dust generated outdoors may also have been carried into the plant by the wind blowing through open doors.

In Plant B, no local exhaust ventilation was observed, and the dilution air supply was through open doors. Again, air drafts may have helped to disperse Pb-containing particles to adjacent workstations as well as to the office and canteen areas. In the stacking/assembling section there were exhaust fans in the walls and the ceiling that provided general dilution ventilation but not at the point sources of emissions.

In both plants, production workers were provided with personal protective equipment including overalls, gumboots, and gloves, in addition to the respiratory protection. Both plants had changing, washing, and shower facilities. However, production workers had their meals while wearing their work clothes and smoked without first washing their hands. There was little evidence that the shower facilities were used, and dirty work clothes were observed to have been stored with clean ones.

DISCUSSION

Previous studies have documented high levels of Pb exposure among workers in battery recycling and manufacturing facilities in developing countries. This study showed that not only did the mean airborne Pb levels exceed the OSHA PEL in all monitored areas of the two plants (including the office and eating areas), but the PbB level of every sampled worker exceeded 30 µg/dL. Blood lead levels more than 30 µg/dL are associated with adverse health effects. Kosnett et al. recommend the medical removal of Pb-exposed workers, if a single PbB concentration exceeds 30 µg/dL, until the levels fall below this criterion value.

One limitation of the air sampling study was that area monitoring, not personal breathing zone monitoring, was conducted. It is expected that workers located close to a point source of Pb emission would have a higher airborne Pb exposure level than reflected by the area sample results. It should be noted that filtering-facepiece respirators (dust masks) were used in both plants by production workers, although workers

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CONCLUSION

This study provides a baseline of the Pb exposure levels in a battery recycling and a battery manufacturing plant in Kenya. We believe that the Pb exposures measured in this study are representative of the Pb exposures in similar and related establishments in Kenya.

Results of this study were shared with the relevant authorities to serve as a basis for developing policies on Pb exposures of affected workers. Specific recommendations were made to address Pb exposures through proper engineering controls, good work practices, respiratory protection, and personal hygiene. It is expected that on complete implementation of the recommendations, a follow-up study will be conducted to assess the Pb levels in these facilities.

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