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Workplace and ambient air monitoring of lead & other emissions at lead acid battery recycling units and survey of health impacts on workers

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Abstract

Battery recycling units can result in significant amount of particulate emissions, especially lead, with potential to cause adverse health effects on the workers and the nearby community. The 24 registered lead acid battery recycling units in Gujranwala generate high emissions of lead (Pb), carbon monoxide (CO), sulfur dioxide (SO_2) and particulate matter 10 (PM_{10}). The present study aimed at monitoring air emissions at workplace and surrounding residential areas of these units and identifies impacts on the health of workers. For this purpose, workplace, as well as ambient air monitoring of surrounding areas, was carried out. Questionnaire survey was administered in order to gather information regarding workplace safety conditions, and health of workers. The results showed higher Pb concentration in each unit with the highest concentration of 3000 µg/m³ measured in Mohammad Hafeez condemned battery unit and lowest 87 µg/m³ in Admiral Battery Works. The highest concentration of SO_2 was 0.163 ppm while lowest was 0.05 ppm .The highest CO concentration was 310 mg/m³ and lowest was 8.2 mg/m³ compared to OSHA standard of 57 mg/m³.The highest PM_{10} concentration was 1689 µg/m³ and lowest was 317 µg/m³ . Among residential areas around recycling units the highest concentrations of Pb, CO, SO_2 and PM_{10} were observed at Bajwa Road (Pb as 1870 µg/m³, CO 47.3 mg/m³, SO_2 as 0.086 ppm and PM_{10} as 449.2 µg/m³). The lowest concentration of Pb was 500 µg/m³ in Gala Kausar Fanwala which also showed lowest CO as 20.6 mg/m³. The lowest concentrations of SO_2 and PM_{10} were monitored in Kangniwala, as SO_2 was 0.049 ppm and PM_{10} was 315 µg/m³. The working conditions at these units were also un satisfactory with lack of health and safety. protective measures.

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Introduction

Globally, fifty percent (50 %) of lead production is obtained from recycling of lead acid batteries. In developing countries recycling of used lead acid batteries is increasing, without enforcement of necessary relevant infrastructure and regulations, which results in generation of large quantities of emissions that poses a greater risk of adverse impacts.

A review of published literature on exposure from lead acid battery manufacturing and recycling units in 37 developing countries showed that lead exposure is higher in developing countries. The workers showed an average blood lead level (BLL) of about 64 µg/ dL in recycling units of batteries while Pb concentration in air was 367 µg/ m^3 that is 7 times greater than permissible exposure limit set by US Occupational Safety and Health Administration. Whereas among children living near battery units, the BLL was 19 µg/ dL,13 times higher than the BLL observed in children in the United States (Gottesfeld and Pokhrel, 2011).

The environmental laws and standards regulating recycling of lead acid batteries, particularly in Europe, are very stringent and hence difficult to meet due to which most of the lead is dumped in landfills. It is also due to this reason that recycling has been shifted to developing countries, where enforcement of environmental standards is not so stringent (Kellow, 1999). So, in most of the cases, people living in developing countries are affected by lead exposure with children being more vulnerable as it is dangerous for them even at low exposure limit (Meyer *et al*., 2008). Exposure to lead causes adverse health impacts. Pb contaminated dust and soil particles cause adverse health impacts and lead exposure affected almost every system of the body (Roussel *et al*., 2010).

Lead is associated with neurotoxic impacts and adversely affects central nervous system, cardiovascular system, reproductive system, hematological system, kidney and decreased IQ level. Absorption capacity of lead in children is higher as compared to adults. It is reported that exposure to lead caused impaired cognitive and behavioral development in children (Lidsky and Schneider, 2003). Even at lower exposure rate, it's negative impacts on their neurological behavior in the form of speech disorder, decreasing short term memory, reading disabilities, learning capacity, problems in hand-eye coordination, and hyperactivity has been observed. Other impacts on children include disorders associated to gastrointestinal, kidney, homatopoietic system. It also causes anemia and hearing disabilities (Fewtrell *et al*., 2004; Fonte *et al*., 2007; Meyer *et al*., 2008).

Lead exposure causes osteoporosis, the urinary lead level having more stronger relationship with osteoporosis as compared to blood Pb level (Sun *et al*., 2008). Moreover, women are more vulnerable to exposure as compared to men especially, pregnant women. Transfer of lead from mother to fetus has also been reported. A study by Schell (2003) indicates relationship between maternal and umbilical cord blood lead level. If a pregnant woman is exposed to Pb in her first trimester of pregnancy then fetus experiences greater adverse neurodevelopment impacts as compared to exposure during second and third trimester of pregnancy which results in decreasing intelligence of child even after control of other prenatal and postnatal lead measurement (Schell *et al*., 2003; Sun *et al*., 2008).

In Pakistan mostly used lead acid car batteries are recycled. Basically the recycling of lead batteries is done on small scale and for that purpose, simple method is adopted in which Pb is recovered by melting down of battery in the furnace. During this, significant emissions are generated and in most of the cases emission control devices are not installed so these emissions are directly released into the air. The workers as well as the nearby community, is adversely affected due to exposure to emissions. Lead has been widely accepted as hazardous and poses numerous health and environmental implications. The present study would cover all used lead acid battery/

condemned battery recycling units in the city of Gujranwala which is located 63 km north of the provincial capital city Lahore.

The present study was carried out to determine the emissions from recycling units and assess the health & safety conditions of the workers in these units. This has been achieved by monitoring of air emissions in the workplace and ambient air of areas surrounding these units. Moreover, the health and safety survey was conducted among workers of the recycling units, so as to determine impacts on their health.

Methodology

Primary data for the study was collected with the help of questionnaire related to administration of lead acid battery recycling units, workers of these units and community living around these units. Monitoring of workplace and surrounding ambient air was carried out to determine levels of Pb, PM, CO and SO_2.

Study Area Selection, sampling and analysis of selected parameters:

- **Selection of study area:** The present study was conducted at all 24 and registered lead battery recycling units in Gujranwala. These units are located in Industrial Estate II, Bajwa Road, Sultan Estate near Main Drain, Gala Kausar Fanwala and Kangniwala Chowk Gujranwala. There are residential areas around these recycling units, which include Mohafiz Town, Kangniwala, Gala Kausar Fanwala and Bajwa Road. **Fig. 1** shows the location map of the recycling units in Gujranwala.

Monitoring/ measurement of air emissions

The air quality inside and around recycling unit was determined by measuring selected parameters that include Pb, PM_{10}, CO and SO_2. These units work operate on two 8 hours shifts.

Sampling of workplace air emissions was done at a distance of 1 meter from stack of recycling unit, as per equipment operational instructions. This monitoring was done in low season when less battery scrap was available for recycling. Monitoring sites for residential areas were selected on the basis of distance (nearest) around these recycling units.

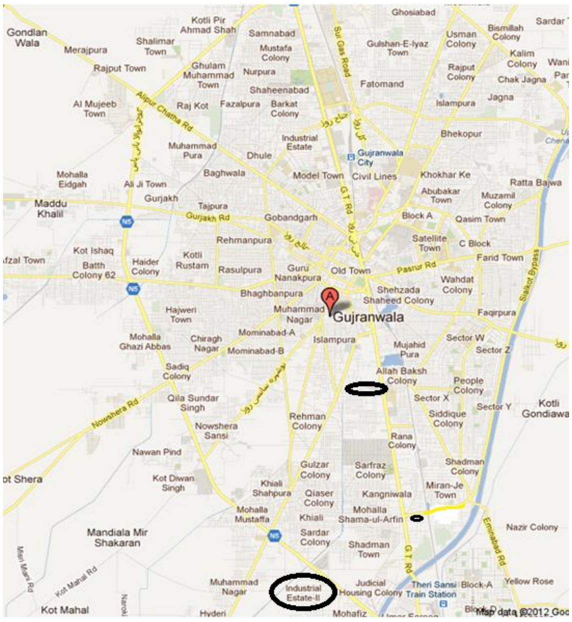

Fig. 1. Map of Gujranwala highlighting location of lead acid batteries recycling units.

Table 1. Equipment detail and monitoring hours of ambient air emission in workplace and surrounding areas of lead acid battery recycling units.

Parameter	Equipment/model	Time/Hours of monitoring
Lead	Lead in air sampling kit (LaMotte code: 7440)	8 hours
Carbon monoxide	GasAlert EXTREME Single gas detector (BW Technologies by Honeywell)	8 hours
Particulate matter 10	PM sampler (MiniVol Portable Air Sampler) The sampling technique used is a modification of the PM_{10} reference method described in the U. S. Code of Federal Regulations (40 CFR part 50, Appendix J).	24 hours
Sulfur dioxide	SO_2 in air sampling kit (LaMotte code: 7714)	8 hours

Estimation of air emissions

The parameters measured were lead (Pb), Particulate matter 10 (PM_{10}), sulphur dioxide(SO_2) and carbon monoxide (CO). Table 1 illustrates apparatus detail and time weighted average for monitoring of indoor/workplace and surrounding ambient air emissions.

Health and safety survey

Health and Safety survey of workers in recycling unit was conducted to assess the awareness level/ perception of respondents and identify impacts of emissions on them. For this purpose questionnaires were designed keeping in view workplace safety requirements as per occupational health and safety administration (OSHA) standards; separate questionnaires were designed for gathering information related to health and safety conditions from workers and administration.

The basic criteria used for selection of respondents for survey was based upon workers working inside the recycling units in Gujranwala.

Results and discussion

Lead acid batteries are recycled to extract lead at recycling units. In Gujranwala there are 24 recycling units. The raw material used is in the form of battery scrap, obtained from scrap dealers. All units utilize coal as fuel. Large quantity of air emissions are generated from these units since there is no emission control mechanism in place at these units, except one. The storage area of batteries and working area are also not properly designed to minimize adverse impacts.

Recycling units working conditions

Annually 8244 tons of battery scrap was consumed during peak season and 1976 tons during low season. The peak season is when scrap of used lead acid batteries is easily available in large quantities and rate of recycling is high, whereas the low season is when less amount of lead acid battery scrap is available so the recycling rate reduces. These batteries are stored inside recycling units. Among these, twelve percent (12 %) units, stored batteries inside storehouse and remaining eighty eight percent (88 %) stored these batteries in open space. Out of 12% units with storage facility inside the unit premises, only four percent (4 %) had built designated storage place that is sheltered from rain water and heat. In case of leakage of battery contents, there is high risk of contamination as only eight percent (8 %) had designed water drainage system in case of rain. The floors are not acid resistant, constructed from bricks, cement and soil so sulfuric acid present in the electrolyte of batteries can be absorbed by the soil and fumes also inhaled by humans.

Results of air emission Monitoring of workplace and surrounding ambient air of residential areas

In the recycling process significant air emissions are generated in the form of Pb, SO_2, PM and CO. At all 24 recycling units these parameters were monitored and the highest 8 hour average Pb was measured to be 3000 $\mu g/m^3$ while lowest concentration was 87 $\mu g/m^3$. Table 2 & Table 3 show the results of monitoring.

The Pb concentrations at all units were very high and well above the OSHA standard (50 $\mu g/m^3$) The highest 8 hour CO concentration was 310 mg/m^3 and lowest was 8 mg/m^3, whereas the standard set by OSHA is 57 mg/m^3 for CO. The highest 8 hours SO_2 concentration was 0.163 ppm and lowest was 0.05 ppm. The highest workplace concentration of respirable PM_{10} was 1689 $\mu g/m^3$ and lowest concentration of respirable PM_{10} was 317 $\mu g/\ m^3$ [Refer Table 2].

The lowest contents of Pb, CO, SO_2 and PM_{10} was observed in Admiral Battery works and the reason is that it was the only recycling unit that has treatment technology installed for control/minimization of emissions generated during recycling process.

Lead level in ambient air at Bajwa Road was highest among residential areas, that was 1870 $\mu g/m^3$ and lowest concentration was 500 $\mu g/m^3$ in Gala Kausar

Fanwala. Bajwa Road also showed highest concentrations of CO, PM_{10} and SO_2 as well which were 47.3 mg/m^3 , 449.2 µg/m^3 and 0.086 ppm respectively. The lowest concentration of CO (20.6 mg/m^3) was monitored in Gala Kausar Fanwala. The lowest concentrations of SO_2 and PM_{10} was monitored in Kangniwala, as SO_2 was 0.049 ppm and PM_{10} was 315 µg/m^3 [Table 3].This monitoring of ambient air was done in low season when less quantity of battery scrap was available for recycling so in peak season the concentration of these emissions in the ambient air is expected to be higher.

The highest content of Pb, CO, PM_{10} and SO_2 was found at Bajwa Road among residential areas because there are 10 lead acid battery recycling units in this area with total recycling capacity (lead acid batteries) of 3456 tons/year during peak season and 779.4 tons/year when recycling rate is lower. The emissions of Pb, CO, PM_{10} and SO_2 was high in the workplace and surrounding residential areas, due to the fact that the emissions generated were released in the air as such without treatment and processing for reduction or minimization of pollutant concentration. Studies elsewhere have also shown that in developing countries, the rate of lead recovery varies and recycling methods are also not very efficient so Pb emissions are higher in the atmosphere (Mao, 2008). A study based on literature from developing countries shows that highest arithmetic mean airborne lead was observed in China which was 1260 µg/m^3, and the mean was 367 µg/m^3 (Gottesfeld and Pokhrel, 2011). It is also reported that in most of the recycling processes of lead acid batteries, Pb and SO_2 were emitted in the atmosphere (Sommez and Kumar, 2009). Generation of emissions of lead in the form of dust particles and vapors, SO_2 and CO and production of slag was also reported in lead batteries recycling processes so there is need of technological improvements in the recycling process. Lead dust also contains some sulfur content so if it is released in the atmosphere without proper treatment it affects not only workers of the unit but also surrounding residents (Kreusch *et al.*, 2007; Lee, 2009).

Table 2. Work place Concentration of Pb, CO, SO_2, PM_{10} emissions in lead acid battery recycling units of Gujranwala.

Sr no.	Name of recycling units of lead acid batteries	Lead (µg/m^3) 8Hrs Average	SO_2 (ppm) 8Hrs Average	CO (mg/m^3) 8Hrs Average	PM_{10}(µg/m^3) 24 Hrs Average
1	Admiral Battery Works	87	0.05	8	317.21
2	Mukhtar Hussain condemned battery unit	819	0.1146	22	514.3
3	Abdul Ghafar condemned battery unit	2500	0.144	73.2	991.3
4	Mohammad Asif condemned battery unit	1367	0.12	47.1	598.61
5	Khalid Hussain condemned battery unit	976	0.123	21	587.3
6	Asif condemned battery unit	2345	0.148	89	1462
7	Nasir Mehmood condemned battery unit	2876	0.156	93	1689
8	Abid condemned battery unit	2543	0.148	86.3	1153
9	Amir and Delaweer condemned battery unit	1452	0.119	29.45	679.34
10	Mohammad Munawar condemned battery unit	1253	0.10	41	621.3
11	Shahbaz condemned battery unit	1246	0.094	310	797.49
12	Mohammad Hafeez condemned battery unit	3000	0.161	128	1472
13	Mohammad Siddique condemned battery unit	1980	0.132	117	987
14	Mohammad Yousaf condemned battery unit	1740	0.122	29	902.4
15	Saleem condemned battery unit	1200	0.126	40	716.7
16	Sadiq condemned battery unit	1900	0.128	24	955.1
17	Haider Ali condemned battery unit	1400	0.126	11	886.32
18	Malik Manzoor condemned battery unit	1670	0.114	21	812
19	Mehr Mohammad Saleem condemned battery unit	2900	0.163	198.31	1581
20	Mohammad Asghar condemned battery unit	2100	0.156	92	978
21	Zahid condemned battery unit	2350	0.146	72	1032
22	Naseer condemned battery unit	1300	0.126	40	712.3
23	Sain Abdul Ghafoor condemned battery unit	2400	0.13	28	995.4
24	Irfan condemned battery unit	1600	0.126	101	845.7
	OSHA / U.S standard	**50**	**5**	**57**	**-**

Table 3. Concentration of Pb, SO_2,CO, PM_{10} emissions in surrounding areas of lead acid battery recycling units of Gujranwala.

Serial no.	Names of areas	No. of recycling units in/around residential area	Pb (µg/m³)	SO_2 (ppm)	CO (mg/m³)	PM_{10} (µg/m³)
1	Mohafiz Town Gujranwala	11	1000	0.055	36.34	327.1
2	Bajwa Road Gujranwala	10	1870	0.086	47.3	671
3	Gala Kausar Fanwala Gujranwala	2	500	0.084	20.6	449.2
4	Kangniwala Gujranwala	1	1230	0.049	32.5	315
5	Gondalawala Gujranwala (control)	0	0.05	0.03	0.02	197

Results of survey of workers in lead acid battery recycling units

In order to identify, the health impacts a survey was conducted among workers of recycling units. In the workers survey, 87 male workers participated out of which thirty eight percent (38%) were aged between 15-30 years, thirty four percent (34%) between 30-45 years, sixteen percent (16%) between 45-60 years and twelve percent (12%) below 15 years. All these workers were below matriculation so they were not aware of legislation that governs health and safety of workers and also about health and environmental risk posed by emissions generated by recycling of lead acid batteries. Ninety seven percent (97%) workers worked in processing units of recycling plants and three percent (3%) handled batteries. Among these eighty five percent (85%) were working for 8 to12 hours and fifteen percent (15%) work duration was 4 to8 hours. Sixty eight percent (68%) work in night shift and remaining thirty two percent (32%) worked during the day shift. There is no policy for health and safety of workers inside the recycling units and in just five percent (5%) units workplace practices were implemented which were merely in the form of prohibition of smoking.

Fire and emergency management plan was implemented in only one percent (1%) units and first aid facility was available in fifty six percent (56%) units. There was no proper ventilation system in any of the recycling unit and monitoring of emissions of workplace by concerned authority was also not done. So workers were exposed to emissions that adversely affected their health because ninety nine percent (99%) workers had direct contact with batteries during working and among them just forty percent (40%) workers were provided personal protective equipment (PPEs) in the form of gloves. Manual breaking of battery was done at all recycling units which generated dust, containing respirable Pb particles, but not a single worker used mask and just thirty nine percent (39%) used gloves during battery breaking process. Similarly respirator was not provided in any of the recycling unit. So the chances of exposure of workers to the emissions generated from these recycling units increases. It has been reported that in the lead acid battery recycling units PM and Pb are usually present in very high concentrations and these PM are of different sizes including PM_{10} that enters in human body by inhalation or ingestion (Uzu *et al*., 2011). Moreover, Bhagwat *et al*., (2008) reports that since the manual process is adopted for recycling of lead batteries on small scale of industrial units so there are poor hygiene conditions for workers and hence they are exposed to emissions.

The present study has shown that Pb content. PM_{10}, CO and SO_2 were also above standards. The working conditions of lead batteries recycling units were not good. According to U.S OSHA the health and safety conditions should be controlled, to minimize lead exposure, through engineering controls that include installation of local exhaust ventilation system, isolation of contaminated area where lead is generated so that remaining work area can be protected from emissions, through administrative actions that included limiting workers duration of exposure to emissions, enforcing shower and change of contaminated clothes before leaving for their homes and through PPE that included provision of PPEs and protective clothing and enforced to use them. But in the present case, none of such standard practices was being followed. Beside this the recycling units were not properly built, as in most of the cases storage facility was inside units and it was sheltered by roof made up of tin in some cases with two sides covered and two open. There was no proper door or gate of storage area that isolated it from other sections of recycling units. Besides this, in all units, the washing area was openly built where workers washed lead obtained from solid waste produced during recycling that was reprocessed for extraction of remaining lead. Battery breaking was carried out with hammer and axe and lead dust was generated in this process but masks were not provided in any of the unit. Special clothes that help to reduce transfer of lead contamination to the houses and families of workers were not issued in any of the unit and there was also no provision of regular medical checkup of workers by the concerned authorities of the units. Workers don't change their clothes, as should be the standard practice, before leaving the workplace so the contaminants are not transferred to their homes in order to prevent adverse effect on their families.

The workers survey showed that they suffered from health issues in the form of lungs disorders in fourteen percent (14 %) cases. Thirteen percent (13%) suffered from poor appetite, seven percent (7%) complained of hypertension, while five percent (5%) anxiety. Six percent (6%) workers indicated loss in weight, three percent (3%) irritability, four percent (4%) loss in memory, one percent (1%) vomiting, one percent (1%) constipation, four percent (4%) kidney disorders, seven percent (7%) stomach disorders and twenty seven percent (27 %) have headache. The symptoms were observed in seventy five percent (75%) workers since less than 5 years while twenty five percent (25%) workers had symptoms since 5-10 years. More adverse impacts were reported by workers who have been working from 5-10 years in the recycling units, aged between 30-60 years, as compared to workers who have less than 5 year of work related exposure/duration in the recycling units. Ninety seven percent (97%) of these effected workers were related to processing unit so they were highly exposed to emissions.

Conclusion

Air emissions of lead, particulate matter and carbon monoxide in ambient air of workplace and surrounding residential areas are very high. Health and safety practices have not been implemented at these units. Residential areas were built along recycling units or industrial estates where recycling units were present. Hence, emissions generated from these recycling units pose potential adverse health impacts on the community living in these residential areas. Regular workplace monitoring was not carried out by the authority and workers were adversely affected due to exposure to emissions.

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