Safety and Health at Work 15 (2024) 114–117

Contents lists available at ScienceDirect

Safety and Health at Work

journal homepage: www.e-shaw.net

Short Communication

Exposure Assessment Study on Lithium-Ion Battery Fire in Explosion Test Room in Battery Testing Facility

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ARTICLE INFO

Article history:
Received 21 August 2023
Received in revised form
10 October 2023
Accepted 19 November 2023
Available online 21 November 2023

Keywords:
Battery testing facility
Exposure assessment
Fire
Lithium-ion battery

ABSTRACT

A lithium-ion battery is a rechargeable battery that uses the reversible reduction of lithium ions to store energy and is the predominant battery type in many industrial and consumer electronics. The lithium-ion batteries are essential to ensure they operate safely. We conducted an exposure assessment five days after a fire in a battery-testing facility. We assessed some of the potentially hazardous materials after a lithium-ion battery fire. We sampled total suspended particles, hydrogen fluoride, and lithium with real-time monitoring of particulate matter (PM) 1, 2.5, and 10 micrometers (μm). The area sampling results indicated that primary potential hazardous materials such as dust, hydrogen fluoride, and lithium were below the recommended limits suggested by the Korean Ministry of Labor and the American Conference of Governmental Industrial Hygienists Threshold Limit Values. Based on our assessment, workers were allowed to return to work.

A lithium-ion battery is a rechargeable battery that uses the reversible reduction of lithium ions to store energy and is the predominant battery type in many industrial and consumer electronics. We conducted an exposure assessment five days after a fire in a battery-testing facility.

Gyungi-do province, Republic of Korea, is the location of the battery testing facility. The company tests for the safety characteristics of batteries, including electrical safety, vibration characteristics, explosion safety, and water protection. The building is a four-story building solely dedicated to battery safety testing. The fire started at midnight Friday on September 30, 2022, a room that tests for battery explosion and is on the first floor of the building. A technician left a lithium-ion battery in the explosion test equipment for the weekend, which unexpectedly caused the fire. Staff from another building observed the fire and reported it to the local fire department. The fire department extinguished the fire but completely damaged the explosion testing room. Smoke from the fire spread into the other portions of the building. There was no determination of cause for this fire. There were no human casualties from the fire.

The company asked our team to assess exposure to potentially hazardous materials after the fire to evaluate whether workers in rooms in the building outside the room with the fire were cleared to return to work. An investigation by the company's insurance group prevented our assessment of the room where the fire started. Our team assessed the exposure on the first, second, third, and fourth floors.

Lithium-ion batteries are generally safe and are unlikely to fail or catch fire with proper storage, charging, and discarding

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https://doi.org/10.1016/j.shaw.2023.11.007

Table 1
Sampling locations and date

Site	Particle counter Date and duration	PVC filter (1 L/min) Date and duration	MCE filter (2 L/min) Date and duration	Black carbon
1st floor, EMC (office)	–	10/5/22 14:16 ~ 20:16	10/6/22 —	-
1st floor, EMC (office)	–	10/6/22 10:10 ~ 11:00	10/6/22 10:00 ~ 11:00	-
2nd floor	10/6/22 10:13 ~ next day 15:54	10/5/22 14:18 ~ 20:16	10/6/22 10:02 ~ 11:02	10/12/22 11:30 ~12: 30
3rd floor (lab)	10/6/22 10:21 ~ next day 15:53	10/5/22 14:20 ~ 20:20	10/6/22 10:04 ~ 11:04	10/12/22 12:32 ~ 14:32
4th floor (lab)	10/6/22 10:25 ~ next day 15:48	10/5/22 14:22 ~ 20:22	10/6/22 10:06 ~ 11:06	10/12/22 14:34 ~ 16:25

EMC, electromagnetic compatibility testing room; PVC, polyvinylchloride; MCE, mixed cellulose ester.

procedures. However, staff from the Epidemiology Directorate's Hazard Analysis Division conducted a search of the Consumer Product Safety Risk Management System (CPSRMS) for incidents from January 1, 2012, to July 24, 2017, and reported that more than 25,000 incidents of overheating or fire hazards with more than 400 types of consumer products [1]. As an example of safety concerns from lithium batteries, passengers are prohibited from onboarding spare lithium batteries in checked baggage, including baggage checked at the gate or onboard the aircraft on commercial aircraft are prohibited from onboarding [2]. The US EPA report found 64 waste facilities that experienced 245 fires from 2013 to 2020 that were caused by, or likely caused by, lithium metal or lithium-ion batteries [3].

Lithium-ion batteries have three main components: the cathode, anode, and electrolyte. The cathode is typically made of a lithium metal oxide such as lithium cobalt oxide ($LiCoO_2$), lithium manganese oxide ($LiMn_2O_4$), or lithium iron phosphate ($LiFePO_4$). The anode is usually made of graphite or other forms of carbon. The electrolyte is typically a lithium salt dissolved in an organic solvent [4].

The safety of lithium batteries is a critical concern, as they can overheat, catch fire, or even explode under certain conditions. Lithium-ion battery testing involves a series of procedures and tests conducted to evaluate lithium-ion batteries' performance, safety, and lifespan. Battery testing involves using specialized equipment and software to simulate real-world conditions and measure parameters such as capacity, voltage, temperature, and resistance. Battery testing is done at the individual cell, module, or complete battery pack level. To ensure the safety of lithium-ion batteries, relevant procedures, and international organizations developed various safety standards and certifications [5–7]. The following precautions are procedures recommended when testing a lithium battery: 1) use of a resistant enclosure or chamber with adequate ventilation and cooling to prevent overheating, 2) monitor temperature, voltage-current, or impedance during the testing process, 3) equip proper fire extinguishing equipment and 4) dispose of damaged battery properly [8–11]. Examples of standards and regulations include IEC 62133-2 [5], UL 1642 [12], UL 2054 [13], CTIA Battery Certification Program [7], and IEEE Standard 1625 [14].

A battery cell can self-heat uncontrollably, leading to a lithium-ion battery fire, and is called a thermal runaway. The heated cell creates gases to such a degree that fire begins [15,16]. A single cell undergoing thermal runaway can precipitate other cells to undergo thermal runaway, much like a chain reaction, and cause the whole battery to explode and catch fire. There are different reasons why thermal runaway can happen, including the battery operating at an unsuitable temperature; a damaged battery due to piercing, smashing, or being dropped; the battery charged or discharged too fast or too much; or a manufacturing defect [15–17].

While a lithium battery fire generates a considerable amount of heat, the fumes from the fire are critical risks and, in some circumstances, can be a more significant threat than the heat, particularly to people in confined environments, such as rooms of buildings. The list of possible chemical agents emitted in a fire can be extensive. Some examples include phosphoryl fluoride, hydrogen fluoride, methyl carbonate, diethyl carbonate, ethylene carbonate, carbon monoxide, and carbonyl sulfide [18,19]. For example, given sufficient air concentration and exposure, hydrogen fluoride is a highly corrosive and toxic gas causing severe damage to the respiratory system; phosphorus oxides are highly irritative to the eyes, nose, throat, and lungs. Also, given sufficient air concentration and exposure, arsine flammable can cause hemolysis, kidney failure, and death. Carbon monoxide, also given sufficient air concentration and exposure, is a colorless, odorless, and poisonous gas that can cause headache, nausea, dizziness, and death [20].

We conducted our investigation five days after the fire. We focused on sampling locations on individual floors of the building. See Table 1. Total particulates were sampled according to the NIOSH 0500 method [21]. Briefly, filtered particles were collected for 6 hours with a 1 L/min sampling pump using a three-stage cassette equipped with a 37 mm, 0.45 μm polyvinyl chloride (PVC) filter. Weight analysis was performed using an electronic balance. The monitoring at the site was conducted for about 30 hours using a real-time monitoring particle counter (AirSens™ PS 1602PM, range

Table 2
Concentrations of total suspended particles (TSP)

Sampling location (date)	Filter weight (before, mg)	Filter weight (after, mg)	Flow rate (L/min)	Sampling time (min)	Mass concentration (mg/m^3)
1st floor EMC (10/5)	18.745	18.806	1	360	0.17
2nd floor (10/6)	12.167	12.169	1	360	0.01
3rd floor (10/5)	18.762	18.841	1	360	0.22
4th floor (10/5)	16.708	16.730	1	360	0.06
EMC (10/6)	18.967	18.976	1	360	0.03

EMC, electromagnetic compatibility testing room.

Table 3
Mass concentration estimated by the Particle counter

	PM1.0 (μg/m^3)	PM2.5 (μg/m^3)	PM10 (μg/m^3)	Total (μg/m^3)
2nd floor	3.561	4.651	8.942	88.158
3rd floor	6.939	8.238	11.136	157.556
4th floor	3.872	4.536	6.344	89.418

PM, particulate matter.

0.25—10 μm, 16 different channels, 1.2 L/min, HCTM, Icheon, Korea). Hydrofluoric acid (HF) was collected for an hour with a 2 L/min sampling pump using a 37 mm, 0.45 μm Mixed Cellulose Ester (MCE) filter and analyzed by an ion chromatographic method according to the NIOSH 7906 test method [22]. Lithium (Li) in the air was collected for 1 hour with a 2 L/min sampling pump using a 37 mm, 0.45 μm MCE filter and analyzed by Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) according to the NIOSH 7300 test method [23].

Compared the sampling results to the exposure limits for chemical and physical exposure factors set by the Korean Ministry of Employment and Labor [24]. The total suspended particle (TSP) exposure limit is 10 mg/m^3 or less [24], and the American Conference of Governmental Industrial Hygienists (ACGIH) recommends exposure to respirable dust as 3 mg/m^3 or less [25]. See Table 2. We also conducted real-time measurements using gravimetric measurement or gravimetric estimation particle monitor. Measurement during the sampling time showed a peak concentration of 2 mg/m^3 on the third floor between 15:00—16:00 (Fig. 1B) and an average of 0.22 mg/m^3. The third floor reported higher levels of total particulates but not for HF or Li; we believe the cause of the high levels of particulates was human activity on that floor. Nevertheless, the peak concentration did not exceed the exposure limits for KMOEL or ACGIH (Table 3).

Given sufficient dose and exposure, HF inhalation causes a burning sensation and sore throat [26]. The US OSHA PEL (permissible exposure limit) sets 3 ppm (8-hour Time-weighted average (TWA)), and the US NIOSH reports a 10-hour REL TWA of 3 ppm (2 mg/mg^3). ACGIH recommends a threshold limit value (TLV) of 0.5 ppm and a 2 ppm TLV-C, which should not be exceeded during any part of the working exposure [25]. And the Korean Ministry of Employment and Labor sets the exposure limit at 0.5 ppm 8-hour TWA [24]. In this environmental measurement, HF was detected below the exposure limit as 'non-detect' and did not exceed the exposure limit 8-hour TWA (Table 4). Li measurement was non-detect in this environmental measurement and did not exceed the exposure limit (Table 5). Still, the exposure limit for lithium hydride set by the Korean Ministry of Employment and Labor is 0.025 mg/m^3 [24], and the TLV of ACGIH is less than 0.025 mg/m^3 [25], so the exposure did not exceed those limits.

Table 4
Hydrofluoric acid concentration in air

Sample number	Sampling location	Result
1	EMC	Not detected
2	2nd floor	Not detected
3	2nd floor	Not detected
4	blank	Not detected
5	3rd floor	Not detected
6	4th floor	Not detected

Table 5
Airborne lithium concentration

Sampling location	Sample number	Flow rate (L/min)	Sampling duration (min)	μg/mL	mg/m^3	Recovery rate (%)
Blank	4	—	—	0.0048	0.0000	100.5
EMC	1	2	60	0.0049	0.0000	100.5
2nd fl	2	2	60	0.0049	0.0000	100.5
2nd fl	3	3	60	0.049	0.0000	100.5
3rd fl	5	2	60	0.0050	0.0000	100.5
4th fl	5	2	60	0.0058	0.0002	100.5

LOD, limit of detection, 0.0006 μg/sample; LOQ, limit of quantification, 0.0019 μg/sample.

In this paper, we have described exposure assessment after a lithium-ion battery fire. We evaluated mainly airborne particulate matter and graphite retardants, a significant component of lithium-ion batteries that could be generated during battery fires. We also measured the air concentration of hydrogen fluoride and lithium, which could be potentially hazardous materials to workers. Our area sampling results indicated that primary potential hazardous materials such as dust, hydrogen fluoride, and lithium were below the recommended limits Korean MOL and ACGIH TLVs suggested. Thus, we recommended that workers go back to their standard daily work. Our studies have some limitations: 1) being unable to measure PAH concentration, 2) being unable to enter and measure the fire-originating site, and 3) identifying the cause of the fire. In addition, other safety checkpoints after the fire, such as structural damage to the building, gas leaks, electrical hazards, and water damage, were conducted by other teams.

Ethical statements

Not applicable.

Conflicts of interest

The authors declare that they have no competing interests.

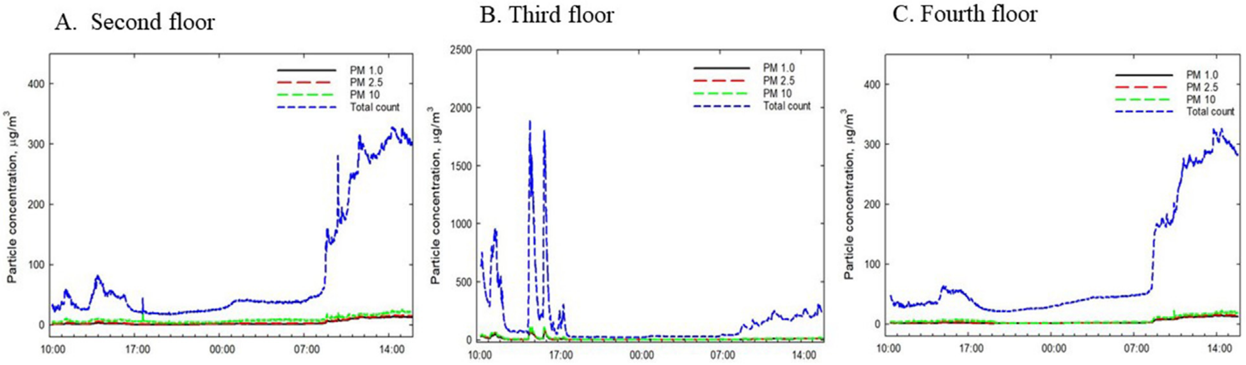

Fig. 1. Real-time measurement of particles by Particle monitor.

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