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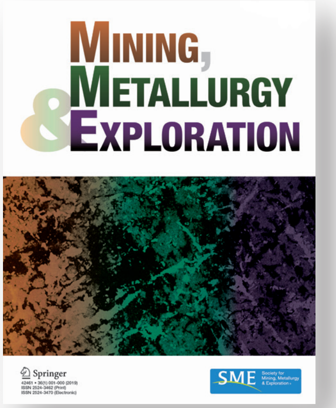

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Invited Extended Abstracts

Comparison of fire suppression techniques on lithium-ion battery pack fires

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Keywords: Lithium-ion battery, fire suppression, water mist, dry chemical

Lithium-ion (Li-ion) battery pack fires pose great hazards to the safety and health of miners. A detailed experimental study has been conducted at the National Institute for Occupational Safety and Health's (NIOSH) Pittsburgh Mining Research Division (PMRD) to investigate the effectiveness of different fire suppression systems on Li-ion battery pack fire extinguishment. Tests were conducted in a well-ventilated container. Two sizes of battery packs (12 V and 24 V) were heated by heater strips to trigger thermal runaway and fire. Water mist with different flow rates, ABC powder, type D dry chemical, and water mist with F500 additives were used as the fire suppression agents. Multiple thermocouples were installed on the battery packs to measure the temperature evolution during the tests. The results indicate that the water mist with F500 additives is the most effective suppressant among the agents tested. Dry chemicals, however, do quench the fire for a moment, but cannot prevent re-ignition of the battery since they do not provide enough cooling. The findings of this paper can be used to develop safer battery fire suppression techniques in mining environments.

Introduction

In the mining industry, Li-ion battery-powered electric vehicles (BEVs) are believed to be a promising replacement for diesel-powered vehicles whose emission of diesel particulate matter (DPM) is a major concern for the safety and health of miners [1]. In a mining environment where fire suppression resources are limited, an effective battery fire suppression technique is critical to the safety and health of miners. Numerous studies have been conducted to investigate the effectiveness of traditional fire suppression techniques on battery or battery pack fires. Unlike traditional fire suppression, battery fire suppression requires extensive cooling even after the fire is visually quenched [2] to reduce battery temperature and prevent re-ignition due to chemical reactions inside the batteries. In this work, detailed experimental research was conducted to investigate the effectiveness of different fire suppression systems on Li-ion battery pack fires. Two sizes of nickel/manganese/cobalt (NMC) Li-ion battery packs and five fire suppression systems were chosen. Results of the fire suppression tests will be discussed and compared.

Results and discussion

Figures 1-3 show a comparison of the sequences of free burn with water mist suppression and dry chemical suppression on a 12-V battery pack. For the free burn case (Fig. 1), smoke was observed to release at about 3.5 minutes after heating started, and the flame started at about 10 minutes. The explosion and fire continued for about 8 minutes before the battery pack burnout. For the water-mist suppression case (Fig. 2), smoke was observed to release at about 3 minutes after heating started, and the flame started at about 10 minutes. Water suppression started at about 13.5 minutes when the flame was fully established. Water suppression was turned off at about 16.5 minutes and the battery pack fire was completely extinguished. There was no re-ignition after the battery fire was extinguished. For the dry chemical suppression case (Fig. 3), the battery fire started at about 10.5 minutes after heating. The suppressant was discharged at 12.5 minutes and lasted for about 45 seconds before the suppressant was depleted. The battery pack was buried under the dry chemical. Shortly after the fire was quenched, re-ignition occurred, then the explosion followed.

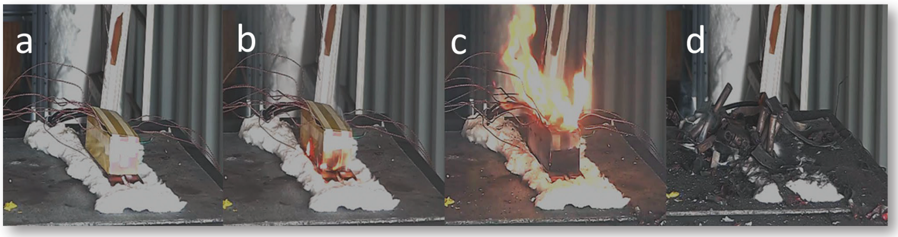

Fig. 1 Free burn: (a) smoke starts, (b) flame starts, (c) explosion and (d) burnout.

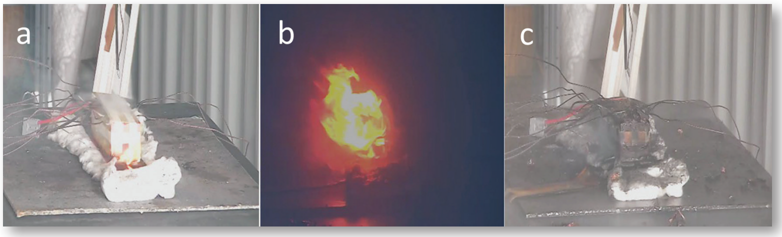

Fig. 2 Water mist suppression: (a) flame starts, (b) suppression starts and (c) extinguishment.

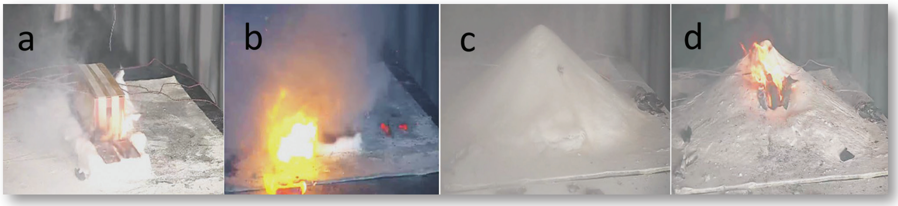

Fig. 3 Dry chemical suppression: (a) flame starts, (b) suppression starts, (c) battery fire quenched and (d) re-ignition and explosion.

Temperatures were compared between the free burn of a 12-V battery pack with water suppression and dry chemical suppression cases. In Fig. 4, the two vertical dashed lines represent the water suppression period or dry chemical suppression period. It was observed that the battery temperatures of the free burn tests were much higher than the water mist suppression test. In the free burn case, batteries went into thermal runaway and caught fire with sharp increases in battery temperatures. In the water suppression case, after water suppression was applied, the two thermocouple temperatures quickly dropped and remained below 200 °C for the rest of the test. No re-ignition was observed. The cooling effect of water suppression was probably the key in containing the fire and preventing re-ignition. For the suppression case, it was observed that after suppression was applied, battery temperatures had a noticeable drop before they went up again due to re-ignition. In this case, the lack of cooling effect afforded by the dry chemical application probably played a major role in the re-ignition as the chemical reactions inside the battery continued despite external flame quenching and air exclusion.

Conclusions

Battery pack fire suppression tests were conducted at the NIOSH Pittsburgh Mining Research Division as part of its continual effort to develop workplace solutions to reduce the risk of mine disasters and mine workers' risk of injuries and fatalities. Water mist with different flow rates and/or additives, type D NaCl and dry chemical ABC powder were used to study their effectiveness in Li-ion battery pack fire suppression. The results indicate that water mist can suppress a small battery pack fire, and its cooling effect prevents re-ignition from occurring. Water mist suppression with F500 as an additive can better suppress the fire. Type D NaCl and dry chemical ABC powder fire suppressants could quench the battery pack fire temporarily but failed to cool the battery, and re-ignition occurred. The results from this study can be used to develop an improved Li-ion battery pack fire suppression system for a mining environment.

Limitations

A limitation of the study is focused on the sample size of agents selected to assess the performance and applicability to mine environment conditions. The study did not evaluate an exhaustive list of different types of suppression agents. Furthermore, the study only focused on the performance criteria to suppress thermal runaway events, and no considerations were made to assess the health and environmental impacts of any of the agents tested. The conclusions drawn from this study speak to the performance of the limited number of agents tested and should not be construed as an endorsement nor a recommendation for use in similar scenarios. Additional testing may be needed to include additional agents and investigate the health perspective of their use. ■

Disclaimer

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

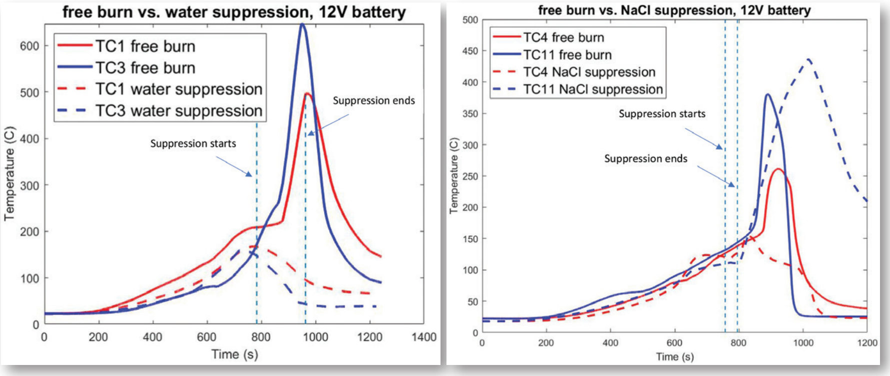

Fig. 4 Temperature comparison for tests.

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Collection in Honor of Dr. Patrick Taylor: All About Metallurgy

Advancements in removing fluorine from copper concentrate

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Keywords: Copper, Fluorine, Smelter, Flotation, Hydrometallurgical method

Copper concentrates have wide application in global smelting operations, comprising primarily of chalcopyrite ($CuFeS_2$) as the principal mineral, accompanied by chalcocite (Cu_2S) and bornite (Cu_5FeS_4) as secondary copper-bearing minerals. However, these concentrates frequently harbor detrimental impurities, notably fluorine ions, which can cause various complications during the smelting process. Moreover, an elevated fluorine content in copper concentrates may entail financial penalties and sales constraints. This review conducts a comprehensive analysis of existing methods for the removal of fluorine, presenting a nuanced assessment of their merits and demerits. It also provides valuable insights into the current landscape of fluorine elimination from copper concentrates and pinpoints pivotal areas warranting future investigation. This review endeavors to serve as a pragmatic resource for researchers and industry professionals operating within this domain.

Background

Copper concentrate, due to copper's outstanding electrical and thermal conductivity, serves as an indispensable raw material across a spectrum of industries encompassing electronics, construction, transportation and healthcare (1). Its importance is paramount in contemporary society and is poised to grow in the coming years.

The smelting of copper concentrate assumes a pivotal role in multiple industries, yet the pronounced fluorine content in the concentrate poses substantial challenges. When fluorine interacts with the silica lining of the smelting apparatus, it generates a volatile gas capable of inflicting equipment damage and posing risks to personnel (2). Furthermore, the emission of elevated fluorine levels from copper smelting operations can cause health and environmental issues (3). Hence, the elimination of fluorine ions from copper concentrate emerges as a matter of utmost importance.