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Numerical Study of the Effect of Smoke Barrier Length Relative to Ceiling Height on Smoke Movement and Fire Behaviour in Battery Electric Vehicle Fires

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Extended Abstract

Fire safety in enclosed parking lots has become an increasingly critical concern, especially with the growing adoption of Battery Electric Vehicles (BEVs). Fires involving BEVs present unique challenges compared to traditional internal combustion engine vehicles, primarily due to their high heat release rates (HRR) and prolonged combustion periods associated with battery fires. In this context, this study investigates the effect of smoke barrier length on smoke movement and fire behaviour in enclosed parking lots, specifically focusing on BEV fire scenarios. Smoke barriers, installed near the ceiling, play a crucial role in controlling smoke flow, preventing its spread to adjacent areas, and directing it toward exhaust systems. However, the optimal configuration of these barriers for BEV fires remains largely unexplored.

This study employs numerical simulation techniques, specifically the Fire Dynamics Simulator (FDS), to analyse the interaction between smoke barriers and BEV fire dynamics. The simulations model a typical enclosed parking lot, where a BEV battery fire serves as the ignition source. A numerical study was conducted to validate the model against experimental data, leading to the development of a customized simulation model. Based on this validated model, the effect of smoke barrier length on smoke movement and fire behaviour has been systematically investigated. The study was conducted in an underground car parking lot measuring 7,800 x 7,800 x 3,250 mm, with the smoke barrier length adjusted to fractions of the ceiling height, specifically 1/5, 1/4, and 1/3 of the total ceiling height.

The results indicate that shorter smoke barriers (e.g., 1/5 of ceiling height) effectively direct smoke toward exhaust systems but allow some lateral spread due to insufficient coverage. Intermediate barrier lengths (e.g., 1/4 of ceiling height) offer an optimal balance by enhancing smoke channelling and stratification without causing turbulence. Conversely, longer barriers (e.g., 1/3 of ceiling height) obstruct natural airflow, leading to reduced visibility in lower areas and localized smoke accumulation. Furthermore, the longest barrier length results in the highest temperature distribution due to smoke retention and heat buildup. These temperature distribution patterns can be used to optimize exhaust system designs.

Additionally, the study examines the influence of barrier length on fire dynamics specific to BEV fires. The results indicate that the CO_2 volume fraction is highest with the longest barrier length (e.g., 1/3 of the ceiling height) compared to other cases. Longer barriers may restrict oxygen supply to the fire, potentially slowing its growth but creating localized heat zones that could exacerbate battery thermal runaway. On the other hand, shorter barriers, while facilitating improved ventilation and smoke clearance, may inadvertently intensify the fire by increasing oxygen availability. The study also evaluates evacuation safety during BEV fire scenarios, emphasizing the importance of optimizing barrier lengths to maintain visibility and ensure safe egress routes. The findings highlight that the unique characteristics of BEV fires, such as prolonged combustion and intense heat, necessitate a re-evaluation of traditional smoke control designs.

In conclusion, this research underscores the critical role of smoke barrier length in managing smoke movement and fire behaviour during BEV fires in enclosed parking lots. By systematically varying barrier lengths relative to ceiling height (1/5, 1/4, and 1/3), the study provides valuable insights for designing safer parking facilities and advancing fire safety standards in response to the increasing adoption of BEVs.

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