Impacts of e-micromobility on fire safety and the new design fire curve for e-bikes

E-micromobility, encompassing various small lightweight vehicles such as bicycles, e-bikes, e-scooters and electric skateboards, is revolutionising urban transportation. The rise of e-bikes and e-scooters poses new safety challenges, notably due to lithium-ion batteries.

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Nevertheless, they offer significant benefits such as emissions reduction and improved accessibility in cities worldwide. Economic factors, including higher fuel prices, have propelled the popularity of e-micromobility. The e-bike market value has grown over ten times larger in many European countries over the past five years. The general development of e-bike markets is spurred by advancements in battery technology, environmental awareness and government incentives. Innovations primarily target battery efficiency and user comfort, while ride-sharing programmes enhance the accessibility of e-bikes. As urbanisation and traffic congestion fuel demand for sustainable transportation, continued investments in research and regulatory changes are expected to further promote e-bike usage.

Growing fire-safety concern

Although e-bikes, or any other electric-driven lightweight vehicles, have many positive impacts on society, fire safety has become a growing concern, especially with their growing popularity. These vehicles, powered by lithium-ion batteries, have been associated with a rising number of fire incidents globally. The statistics reveal that this safety concern is real. In the UK alone, data from 2021 shows 167 fires caused by e-bikes and e-scooters, showing a marked increase from previous years. In New York City (NYC), there were 267 lithium-ion battery fires in 2023, resulting in 18 fatalities and 150 injuries. Such numbers are so high that they can be noticed in the big city like NYC. Additionally, the lack of comprehensive data-collection systems in many countries probably means that many e-bike-driven fires are not accurately recorded in fire statistics. The number of fatalities resulting from e-bike and e-scooter fires has emphasised the urgency to address safety issues. Concerns have been raised about product reliability, correct charging conditions or equipment, and the popularity of DIY solutions, which may contribute to fire risks. Furthermore, media reports indicate a concerning rise in the number of reported e-scooter and e-bike fires, particularly in private homes. In response to these challenges, fire and rescue services have issued warnings and launched campaigns to raise awareness about the dangers associated with e-bike and e-scooter fires. For example, efforts to promote safe charging practices and discourage DIY modifications have been introduced in NYC. Additionally, there is a growing recognition of the need for regulatory measures and safety standards to mitigate fire risks associated with all products.

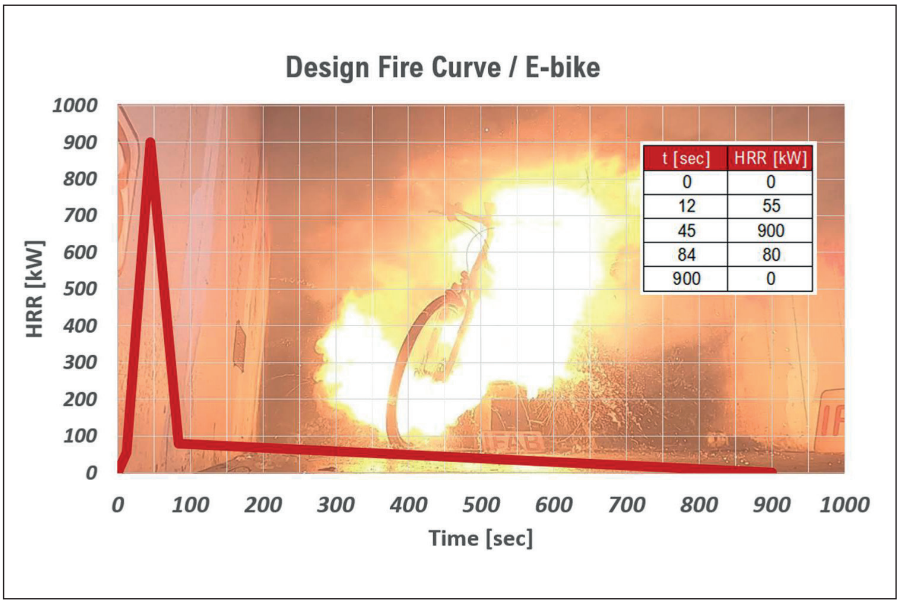
IFAB research project on e-bikes

The Institute of Applied Fire Safety Research (IFAB), Germany, decided to undertake a research project on e-bikes, focusing especially on their fire behaviour. The decision was driven by the acknowledgment of increased safety concerns and the lack of design data on e-bike fires. IFAB faced challenges in conducting fire engineering across various applications due to the difficulty in realistically quantifying the associated risks. These challenges arose from several factors, including heat release rate (HRR), gas formation, gas concentrations and fire propagation. The availability of such data is essential, particularly in quantifying risks as part of the performance-based fire safety design process. Additionally, Computational Fluid Dynamics (CFD) simulations required numerous parameters that were not available. Consequently, IFAB was motivated to conduct full-scale tests with e-bikes in 2022 to enhance understanding in this area.

IFAB, with its EN17025 accredited fire-test laboratory, conducted e-bike tests using its experience in fire testing lithium-ion batteries across various industries like the automobile industry, energy storage systems and recycling. The research project comprised three main parts. Initially, a literature review and engineering analysis assessed typical e-bikes in terms of battery capacity, frame size and combustible materials, and a realistic 'worst-case' scenario was defined. E-bikes matching this scenario were procured for testing. The tested e-bikes contained an aluminium L-size frame, 28in tyres, hydraulic brakes, normal plastic components, a 250W motor and a 660Wh battery.

The test programme included scenarios with a bike bag as well as combinations of two bikes to study fire propagation and more fire load. A comprehensive test protocol outlining different design scenarios was developed to guide the test programme. Experimental tests were conducted in IFAB's test laboratory in Germany. The challenges in measuring HRR due to self-oxidizing battery fires were addressed using multiple simultaneous techniques. These techniques included measuring thermal balance (convective heat transfer), special gas components (using Fourier Transform Infrared Spectroscopy – FTIR) in addition to typical gas measurements of O_2, CO, and CO_2 (oxygen consumption).

The e-bikes were placed in a tunnel with dimensions of 2.5m (w) x 1.25m (h) and forced ventilation at approximately 1m/s to ensure downstream flow of gases. The tunnel was equipped with temperature, pressure, velocity and gas sensors, while experiments were documented using normal and infrared cameras. Various pool fire sizes were used to calibrate the measurement system. Over ten trials with different scenarios were conducted, initiating fires by heating battery cells to induce thermal runaway.



The fire tests generated a lot of data, particularly on gas measurements, providing insights into the quantitative aspects of e-bike fires. The data required a lot of post-processing and analysis though.

New design fire curve

The most important outcome of IFAB's research project is the new design fire curve created specifically for e-bikes. This curve was developed from a series of experimental tests, covering bikes representative of a realistic 'worst-case' scenario, along with several other variations. The design curve shows a peak Heat Release Rate (HRR) of 900kW. Although a higher peak was measured in one fire test, it was deemed statistically unrepresentative as the maximum.

A consistent observation across all tested fires was the rapid development of the fire after the thermal runaway was initiated. This shows that the battery is the predominant element in e-bike fires. Subsequently, once the battery had burned, other combustible materials gradually burn out with relatively low HRR. Even in scenarios involving a bike bag, the additional materials had minimal contribution to the fire when compared to the battery.

The fire behaviour aligned well with real-life incidents reported in the media, demonstrating an efficient release of energy over a short duration. The design curve serves as a valuable tool for assessing fire risks associated with e-bikes. Given that other e-micromobility vehicles employ similar battery technologies, this design fire curve is potential applicable for them as well. It is important to note that this design curve is only for 'standard' bikes without additional batteries and, therefore, may not cover custom-made e-bikes with multiple batteries or any DIY solutions.

Conclusions

In conclusion, the growing popularity of e-micromobility vehicles, particularly e-bikes and e-scooters, has posed unforeseen challenges in fire safety. IFAB's research project represents one step towards understanding and mitigating the fire risks associated with e-bikes. Specifically, the development of a new design fire curve helps to understand the typical behaviour of e-bike fires, providing valuable insights into assessing fire risks and implementing safety measures. The experimental tests confirmed that HRR develops very quickly and can peak at 1MW. Such fires are inherently dangerous due to the toxicity of the gases and their ability to easily ignite surroundings.

Continued research and development efforts are necessary to further enhance the effectiveness of fire-safety measures in the context of e-micromobility. IFAB has also continued testing different suppression technologies, e.g. watermist systems, to mitigate risks. Collaboration among industry stakeholders, regulatory body, and research institutions is essential to develop comprehensive safety standards and promote responsible usage practices.

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