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Methodology of Scale Model Experiment for xEV Fire Torture Standard Test

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Fire torture tests, such as those specified in UN ECE R100, are essential for evaluating the fire safety of lithium-ion battery systems in electrified vehicles (xEVs). However, repeated full-scale tests are costly and impractical during development. This study proposes a reduced-scale experimental methodology based on fire scaling laws to reproduce key phenomena in fire torture tests.

Pool fires and flame plumes are buoyancy-driven phenomena; therefore, **Froude number similarity** is applied. To reproduce flame characteristics, the heat release rate of the scale model must satisfy the following relation:

$$\dot{Q}_m = \dot{Q}_p \lambda^{5/2} \qquad (3)$$

where $\dot{Q}_p$and $\dot{Q}_m$are the heat release rates of the full-scale and reduced-scale models, respectively, and λ\lambdaλ is the geometric scale ratio. The corresponding time scaling is given by

$$t_m = t_p \lambda^{1/2} \qquad (4)$$

indicating that transient fire phenomena proceed faster in reduced-scale experiments. Figure 4 shows flame temperature contour plots obtained from simulations for the full-scale (1/1) model and the 1/2.5-scale model. The reduced-scale results are spatially enlarged for comparison. Despite differences in scale and fuel type, flame height, plume spread, and high-temperature regions show good qualitative agreement, demonstrating that Froude-based scaling and Eq. (3) successfully reproduce dominant flame characteristics.

To reproduce the enclosure surface temperature response, similarity of thermal capacity per unit area is considered. Assuming identical material properties, the plate thickness of the scale model must satisfy

$$d_m = d_p \lambda \qquad (8)$$

Figure 5 shows temperature profiles measured at each location on the enclosure surface. The time axis for the reduced-scale model is corrected using Eq. (4). Similar temporal trends and relative temperature distributions among measurement locations are observed, indicating that the enclosure temperature history is qualitatively reproduced by the proposed scaling model.

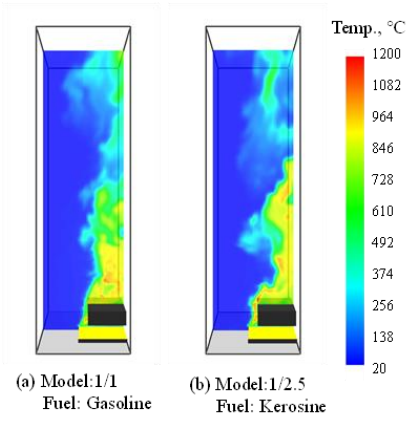

Fig.4 Contour plots of flame temperature obtained from the simulation results: (a) full-scale (1/1) model and (b) 1/2.5-scale model.

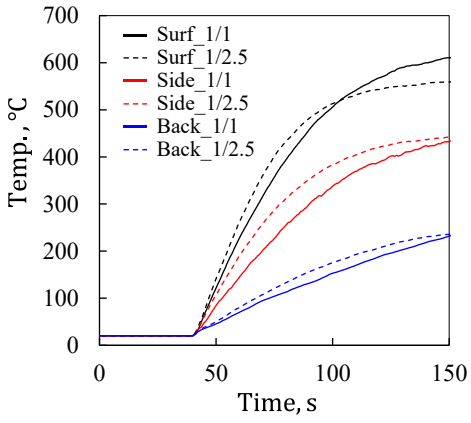

Fig.5 Temperature profiles at each measurement location on the enclosure surface.