Phenomena and Modeling of Container Pressurization Due to Thermal Decomposition of Polyurethane Foams

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Polymer foam encapsulants provide mechanical, electrical, and thermal isolation in engineered systems. In fire environments, gas pressure created by thermal decomposition of organic foams can cause mechanical failure of sealed systems. Systems safety analyses use numerical models to predict heat transfer to encapsulated objects and to predict pressurization and failure of sealed containers. To provide data for evaluating modeling capabilities and determining needed model improvements, heat transfer-pressurization experiments were completed with TDI-based and PMDI-based polyurethane foams [1, 2]. Experiments were done with ½-liter size sealed cylindrical containers exposed to a uniform heat flux at one end (heated plate). The configuration of the experiments and sample orientations (upright and inverted) are shown schematically in Figure 1. Foam density was varied from 160 to 720 kg/m^3.

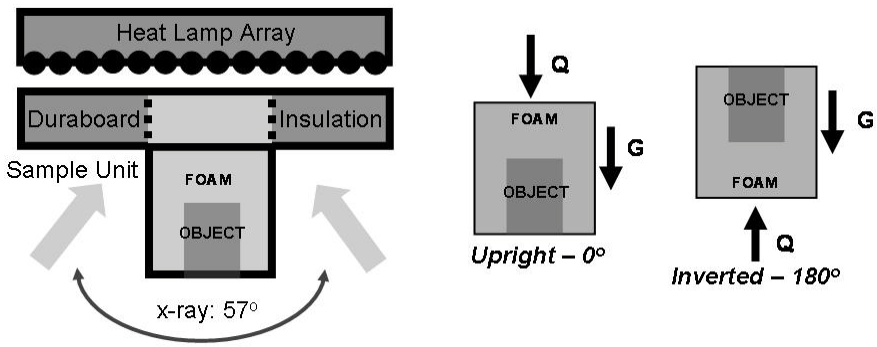

Figure 1. Schematic diagram showing configuration of experiments and sample orientations.

The heated end (plate) of the container was heated at 200 K per minute to a temperature of either 873 K or 1173 K. The temperature was then held constant until the container was vented at 2.5 MPa. Temperatures were recorded from thermocouples attached at 16 locations on the container and at three locations in a stainless steel cylinder that was encapsulated by foam inside the sealed container. Pressures were recorded from a transducer connected to the container. X-ray images, which showed the physical behavior of the foam during the experiments, were recorded at 5-s intervals during the experiments.

Comparison of results from experiments and model predictions had significant implications for future numerical simulations. (1) X-ray images indicated that substantial liquefaction and flow of decomposing foam occurred and was exacerbated by erosive channeling. (2) Depending on container orientation, decomposing foam either flowed away from the incident heat flux or toward it. (3) The time to vent pressure (2.5 MPa) varied significantly with the container orientation, as shown in Figure 2.

Results from numerical simulations also are shown in Figure 2. The current modeling approach uses a 3-D finite element radiation-conduction code to predict heat transfer through the foam to encapsulated objects. Predicted temperatures are the basis for calculating gas generation rates and container pressure. Radiation heat transfer was modeled using a diffusive approximation. Model parameters were evaluated from the literature or independent small-scale experiments. Based on the experimental results, a radiation-conduction approach has shortcomings since convective transport would accompany liquefaction, flow, and erosive channeling. However, the approach was used successfully to model pressurization of containers and heat transfer to objects imbedded in highly charring foam that did not liquefy and flow [3].

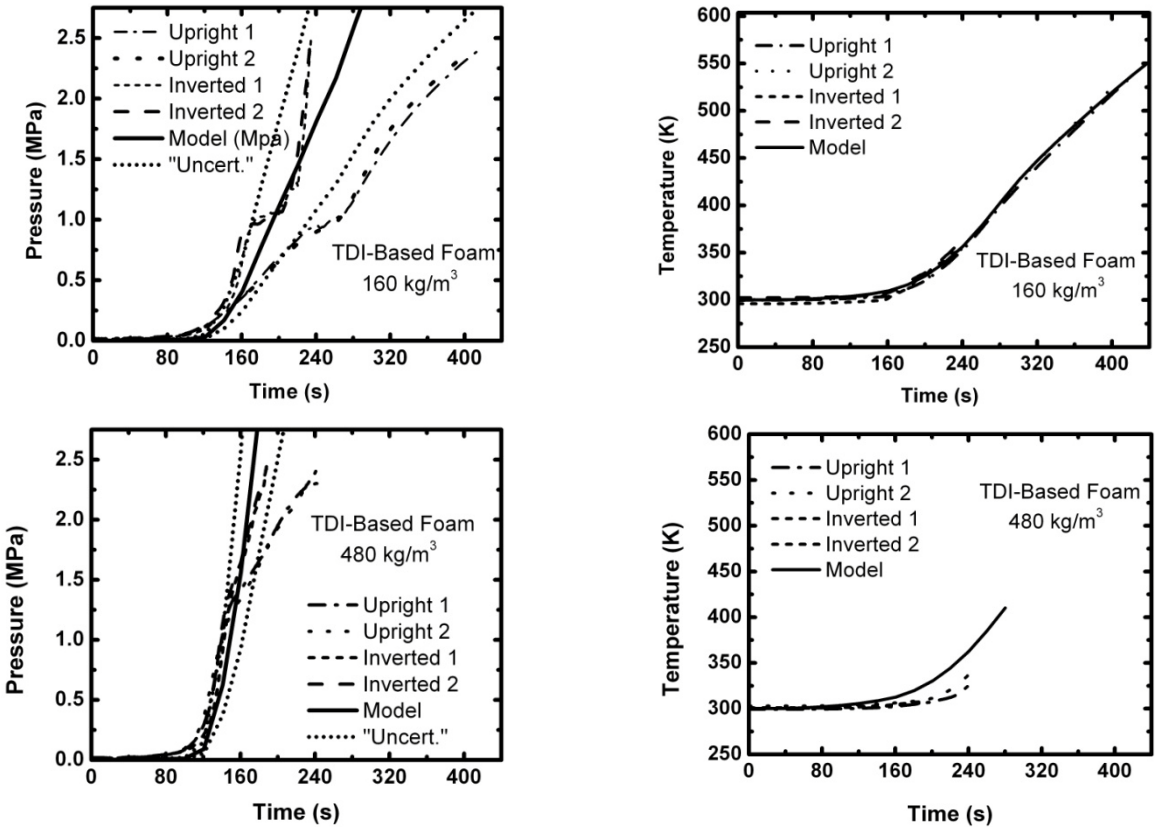

Figure 2. Experimental and numerical results for TDI-based polyurethane foams.

References

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[3] Erickson, K. L., Dodd, A. B., and Hogan, R. E., "Modeling Pressurization Caused by Thermal Decomposition of Highly Charring Foam in Sealed Containers," in Proceedings of BCC 2010, Stamford, CT, 23-26 May 2010.

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