The Response of Residential Smoke Alarms at Low Flow Velocities

Thomas Cleary and William Davis
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD

Smoke particle entry lag in smoke detectors and alarms has been observed to be a function of the local flow velocity that convects the smoke particles into the sensing element. Heskestad [1] proposed a first-order response model that correlated the alarm delay time to the local flow velocity and a single parameter termed the detector characteristic length. Several researchers have correlated detector response using this model and it tends to yield reasonable results at flows on the order of 0.25 m/s and higher, given a detector-specific characteristic length determined from experiments over the flow range. While predictions at lower velocities are usually poor. Cleary *et al.* [2] proposed a four-parameter model based on power law fits of velocity to a characteristic delay time and a mixing time down to velocities as low as 0.02 m/s. The modeled detectors were two styles of commercial ionization and photoelectric heads that were essentially axi-symmetric. Model parameters for representative residential style smoke alarms were not developed.

To obtain model parameters for residential-style smoke alarms, a series of tests was conducted in the fire emulator/detector evaluator (FE/DE). The effects of low flow velocity and approach angle relative to the sensing chamber on the response time delay of three ionization and one photoelectric residential-style smoke alarms were investigated. Alarms tested included modified alarms that provide a continuous voltage signal, - needed to fit the four-parameter model - and un-modified alarms. Cotton wick smolder smoke was produced at nominal alarm-level concentrations for each flow velocity examined. The flow velocity was monitored by a sonic anemometer. When a constant smoke light extinction was reached at the test section, a metal can covering the alarm under test was removed, exposing the alarm to the smoke. The analog voltage signal from each alarm, indicating smoke concentration in the sensing chamber, was acquired. Sensor responses to flow velocities over a range of 2 cm/s to 20 cm/s and three approach angles (0^{O}, 90^{O}, and 180^{O}) were recorded. In tests with un-modified alarms, the time to alarm was recorded.

Each response curve for a given velocity was fitted using a non-linear least squares fitting scheme to obtain a delay time and mixing time. Power law velocity correlations for each characteristic time of a given alarm and approach angle were developed. The four-parameter model was compared to Heskestad's one parameter model over the low flow range.

To adequately predict alarm times at low velocities, additional information is needed. Smoke aerosols are continuously undergoing changes such as coagulation or agglomeration and deposition. Deposition can be due to diffusion losses, inertial losses, gravitational settling, electrostatic and space charge losses, etc. In these tests, steady-state sensor response was observed to be a function of the light extinction value as well as the flow velocity, with the steady-state sensor response decreasing as velocity decreased for a fixed light extinction value. A filter function is proposed to address the change in the steady-state response versus velocity. The filter function accounts for changes in the aerosol properties and concentration as it leaves the source and enters the sensing chamber. More research needs to be conducted to assess the applicability of the filter function to different smoke aerosols.

The characteristic time correlations and the filter functions were used to predict the time to alarm for the un-modified alarms. Given uncertainty in aerosol properties, angular sensitivity, and data scatter, any low velocity smoke alarm prediction should be accompanied by a substantial uncertainty estimate.

References:

[1] Heskestad, G., "Generalized Characterization of Smoke Entry and Response for Products of Combustion Detectors," Proceedings of the Fire Detection for Life Safety Symposium, March 31 – April 1, 1975.

[2] Cleary, T., Chernovsky, A., Grosshandler, W., and Anderson, M., "Particulate Entry Lag in Spot-type Smoke Alarms,"Proceedings. Sixth (6th) International Symposium. International Association for Fire Safety Science (IAFSS). July 5-9, 1999, Poitiers, France, Intl. Assoc. for Fire Safety Science, Boston, MA, Curtat, M., Editor(s), 779-790 pp, 2000.