NISTIR 6242

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Book of Abstracts
November 2-5, 1998

Kellie Ann Beall, Editor

Building and Fire Research Laboratory
Gaithersburg, Maryland 20899

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Particulate Entry Lag in Smoke Detectors

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ABSTRACT

It is well known that smoke detectors do not instantaneously respond to smoke concentration directly outside the detector. The smoke must be transported through the detector housing to a sensing location inside the detector. The sensing time lag is a function of the free stream velocity of the smoke laden air as it approaches the detector. Previous work correlated the detector time lag as a first-order response with a characteristic time defined as L/V, where L is a characteristic length and V is the characteristic velocity (ceiling jet velocity or free stream velocity).

The smart fire panel research program at NIST is evaluating the use of smoke detectors that provide continuous analog output as sensors. These "sensors" then could provide information on the fire to the smart panel. In support of that work, a number of tests were performed in the Fire Emulator/ Detector Evaluator (FE/DE) to characterize the sensing lag time over a range of flow velocities and smoke concentrations for fire ionization and photoelectric detectors that provide a continuous sensor output signal. A model was developed that uses two parameters to correlate the detector time response.

The FE/DE device is a flow tunnel with a cross section of 0.6 m by 0.3 m high at the test section. Air velocity and temperature can be controlled, and provisions to add CO, CO_2, hydrocarbon gases, water, smoke, and other aerosols to the flow are in place or in development. Temperature, velocity and species measurements are recorded at the test section. In the test described here, the temperature, velocity and smoke extinction values across the duct were recorded, in addition to the detector signal.

Smoke was generated by a co-flowing propene diffusion burner. By directing part of the burner smoke output into the flow tunnel, then shutting off the smoke flow to the tunnel, the smoke concentration in the duct steps up, then steps down some time later. Smoke is well mixed in the duct by the time it reaches the test section. Figure 1 and 2 show examples of the effect of flow velocity on the detector signal lag. The optical density curve was generated by a laser attenuation measurement across the duct at the height of the detector.

We chose a simple idealized mixing model consisting of a plug flow region followed by a perfectly stirred region (mathematically, the order of these regions can be reversed with no effect on the model output.) Two parameters are identified, a transport time (δt) associated with the plug flow region and a characteristic mixing time constant (τ) associated with the perfectly stirred region. This model is hydrodynamic only, thus a Reynolds number would correlate the effect of flow and mixing. Particle diffusion is not accounted for since it would only be significant at very low velocities (Reynolds numbers) and the associated detector time lag for a diffusion dominated process would be so long as to make the detector unsuitable as a smart panel sensor. A correlation in the form below is proposed.

$a_i = \alpha_i Re^{\beta i}$

where a_i is either δt or τ, Re is the Reynolds number, α_i and βi are the pre-exponent and exponent to be determined. The mixing model equation for constant velocity is:

$$\kappa Y(t-\delta t) = \tau \; dx(t)/dt + x(t)$$

where Y is the smoke optical density, k is a constant the changes optical density to detector output units, and x is the detector output. The model can be discretized, and for velocity changes, dt and t can be updated in a quasi-steady manner. Thus, one needs the velocity and temperature history at the detector location and the detector output to obtain the smoke optical density at an earlier time.

Figures 3 and 4 show the model results in the form of predicted optical density from the transformed detector signals in Figures 1 and 2 respectively.

Figure 1 - Ionization Detector

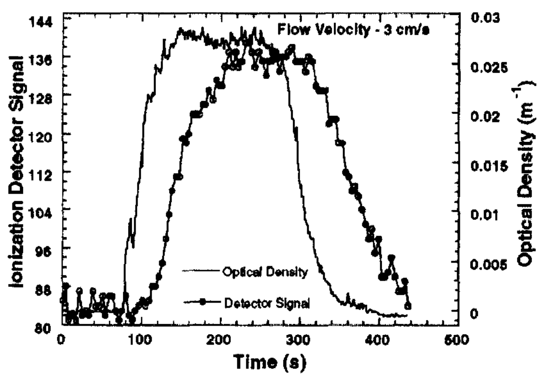

Figure 2 - Photoelectric Detector

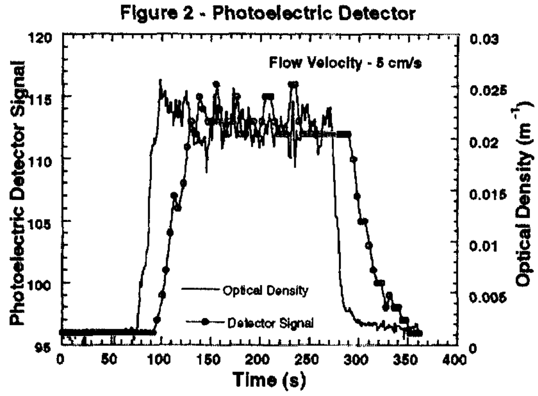

Figure 3 - Ionization Detector

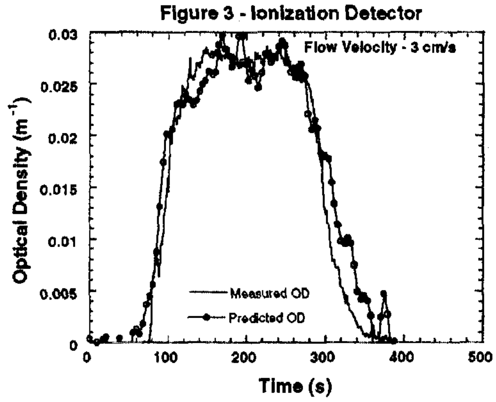

Figure 4 - Photoelectric Detector