NUMERICAL MODEL AND EXPERIMENTAL RESULTS OF FIRE PROTECTION FOAM EXPOSED TO HEAT RADIATION

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Introduction: This work is part of a larger effort to evaluate the performance of fire-fighting agents used to protect structures from heat and fire damage. A joint research program between the University of Maryland and the Building and Fire Research Laboratory at the National Institute of Standards and Technology supported this effort.

The present research looks at fire-fighting (fire-protection) foams designed to stop the spread of fire by protecting structures in or near the fire environment. Protein based compressed air foams are typically used for fire protection applications because of their inherent properties[1]. One application of fire-protection foam is for the protection of dwellings surrounded by combustible vegetation in areas prone to wild fires. In the case of a spreading wildfire, a structure can be coated hours in advance of the fires arrival thereby minimizing the danger to the persons involved. A wildfire can pass a home in five minutes[2] which is shorter than the expected residence time of a properly applied fire-protection foam. Foams will stick under eaves, in corners, and to window glass which are all suspected areas for fire to enter a home. No structure has been lost in California wild fires when properly coated with foam[2].

Previous experimental studies of foams subjected to heat radiation focused on the overall behavior of the foam. Madrzykowski[3] measured ignition delay times for vertical plywood surfaces. This work showed the foam's ability to delay ignition when compared to the use of an equal mass of pure water. Persson[4] studied foams in beakers subjected to heat from a cone radiator. Measurements of foam drainage and foam evaporation rates were obtained for various foams. No reports have been found which measure or predict the behavior of the foam while it is subjected to the radiant heating. This paper investigates the internal behavior of a fire-protection foam exposed to heat radiation.

Experimental Procedures: A repeatable test procedure is developed which subjects foam samples to heat radiation. A vertical steel surface is covered with foam and subjected to heat radiation from a set of gas-fired panels. The apparatus produces a nearly one-dimensional radiation field over a 30x30 cm foam sample. Measurements of applied heat flux and foam temperature profiles are made using foam samples ranging in expansion ratio from 12 to 32. Heat fluxes are adjustable from 10 to 20 kW/m^2. Chubb National Foam's DurraFoam product is used for these experiments because of its ability to stick to vertical surfaces. Foam is produced using a custom built lab-scale foam generator. Details of the experimental procedure along with results are given by Boyd[5].

Modeling and Results Comparison: A model is developed which predicts the behavior of this fire-protection foam subjected to heat radiation. Foam expansion ratio and radiative heat flux are input to the model. A mass and energy balance yield the foam destruction rate and the temperature distribution within the foam. The model separates the foam into its liquid, vapor, and air components. Continuity is satisfied for each. Ideal gas relations, a realistic density function, and foam expansion measurements are used in conjunction with continuity to compute the volume fraction and velocity of each component as a function of temperature.

The model is based on the energy equation which is solved in a coordinate system moving with the foam front. Separate air, vapor, and liquid convection terms are computed. Radiation absorption is accounted for with a volumetric generation term based upon experimental measurements of foam radiation absorption coefficients. A volumetric evaporative term accounts for the latent heat of liquid vaporized within the foam. Liquid vaporization rates are determined from the liquid continuity equation. Saturated conditions and thermodynamic equilibrium are assumed throughout. Thermal diffusion is computed using an experimentally determined thermal conductivity values. A steady state solution is obtained with a second order Crank-Nicolson technique which converges to the solution. The energy balance within the foam is dominated by the generation and evaporative terms which are approximately equal in magnitude. Essentially, the results indicate that the heat is absorbed by the foam and used almost exclusively to evaporate liquid at the point of absorption. The convective terms account for less than ten percent of the energy balance and diffusion is less than three percent.

Experimental results are transformed into a coordinate system which moves with the foam front to facilitate direct comparison with the model results. The average temperature gradient in the central region of the temperature profile is used to compare each of the experimental data sets to the numerical results. On average, the model results predict temperature gradients which are 17 percent lower than the experiments. This is due to aspetcs of the foam behavior which are not represented by the model such as foam relocation on the surface or strong non-uniformities in the transient thickness of the foam layer.

Scaling of the Results: Appropriate dimensionless variables are used to partially collapse the model results. The temperature rise is normalized by the difference between the foam surface and initial temperatures. A mean radiation penetration length is selected as a length scale since the energy balance is dominated by the radiation absorption term. This characteristic length is taken as the inverse of the radiation absorption coefficient. The major terms in the energy balance are proportional to the applied heat flux and are normalized with respect to it and with respect to the characteristic length scale. In dimensionless form, the temperature profiles and major terms in the energy balance do not depend upon the applied heat flux and become solely a function of the foam expansion ratio. The average dimensionless temperature gradient in the central range of the profiles collapses to a single value of - 0.18 for all foam expansion ratios.

Conclusions: This model development, along with the experimental results, sheds light on the mechanisms within the foam which dictate how the foam will absorb and dissipate radiation energy from a nearby fire while protecting the underlying surface. Since absorption is the dominant term in the energy balance, methods to control or change the foams absorption properties will be explored since they may significantly affect the performance of fire protection foams.

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