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Book of Abstracts
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Kellie Ann Beall, Editor

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Gaithersburg, Maryland 20899

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STRUCTURE OF SELF-PRESERVING TURBULENT ADIABATIC WALL PLUMES

by

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Introduction. Plane turbulent wall plumes, caused by sources of buoyancy along walls, are frequently encountered in unwanted fires within structures. Motivated by this observation, the present investigate extended recent measurements of turbulent round and free line plumes in this laboratory [1-5] to consider plane turbulent wall plumes using similar methods. Only weakly-buoyant turbulent wall plumes along smooth plane vertical surfaces with conserved buoyancy flux were considered; this implies flow along an adiabatic wall for a thermal plume.

The present study emphasized conditions far from the source where source disturbances and momentum have been lost. In this region, self-preserving behavior is approximated with scaling similar to self-preserving free line plumes, except for a narrow wall boundary layer that grows more slowly than the outer plume-like region [6]. While such conditions are rarely encountered in practice, self-preserving behavior is still important because it substantially simplifies reporting measurements and evaluating predictions compared to developing flows [5]. Based on recent study of free line plumes [5], however, it is questionable whether self-preserving behavior was achieved during earlier studies of turbulent adiabatic wall plumes, e.g., Ref. 6 and references cited therein.

Experimental Methods. Experimental methods were similar to Sangras et al. [5]. The plumes were observed in an enclosure with porous side walls and ceiling to control room disturbances while not impeding plume entrainment flows. The source slot (876 mm long and 9.4 mm wide) was mounted flush to a flat floor at the base of a vertical plane wall 2440 mm high. End walls (1120 mm wide and 2440 mm high) helped preserve two-dimensional flow.

Two helium/air source mixtures were studied having initial source/ambient density ratios of 0.750 and 0.500 and source Froude numbers of 3.5 and 3.8. Use of gas mixture sources provided an accurate specification of the plume buoyancy flux that is difficult to achieve for thermal plumes [5].

Mean and fluctuating mixture fractions were measured using laser-induced fluorescence (LIF) similar to Sangras et al. [5]. The source flow was seeded with iodine which fluoreses naturally in an argon-ion laser beam having a wavelength of 514.5 nm. For present conditions, effects of differential diffusion of helium and iodine vapor were negligible. Experimental uncertainties (95% confidence) of the measurements of mean and fluctuating mixture fractions were less than 10%.

Results and Discussion. Present measurements of mean mixture fractions are plotted in terms of self-preserving variables in Fig. 1. Results for $z/Z = 0$ and 1/4 agree with each other, confirming the two-dimensionality of the flow. The present measurements yield universal distributions of normalized mean mixture fractions for distances from the source of 92-155 source diameters (or 12-21 Morton length scales). This corresponds to characteristic Reynolds numbers of 3800-6700 which implies reasonably turbulent flows. Other measurements plotted on the figure include the results for adiabatic wall plumes due to Grella and Faeth [6] and Lai and Faeth [7], results for isothermal wall plumes due to Liburdy and Faeth [8] and results for free line plumes due to Sangras et al. [5]. The measurements of Refs. 6-8 all exhibit streamwise variations in terms of self-preserving variables and are for conditions farthest from the source. The isothermal wall plume is somewhat broader than the rest because the low wall temperature forces the maximum buoyancy condition away from the wall [8]. The other adiabatic wall plumes are broader than present observations because they were not obtained far enough from the source to reach self-preserving behavior. The self-preserving free line plume is much broader than the rest which highlights the stabilizing effect of the wall. A negative aspect of wall stabilization, however, is that the inhibited mixing implies longer flames and hotter plumes for wall plumes than for free plumes at comparable conditions which increases their fire hazard.

Measurements of rms mixture fraction fluctuations are illustrated in Fig. 2, along with measurements from Refs. 5, 7 and 8. Maximum absolute mixture fraction fluctuations are larger in adiabatic wall plumes than in free line plumes because maximum mean mixture fractions are larger. Maximum mixture fraction fluctuation intensities, however, are actually larger in free line plumes than in adiabatic wall plumes, e.g., 47% as opposed to 39%, which is another effect of wall stabilization. The other measurements differ from present results because self-preserving behavior was not reached and due to the fundamental differences between the structure of adiabatic and isothermal wall plumes [8].

Nomenclature. b = source width, B_o = buoyancy flux, $\bar{f}$ and $\bar{f}'$ = mean and rms fluctuating mixture fractions, g = acceleration of gravity, x and x_o = streamwise distance and location of virtual origin, y = crosstream distance, z= distance along slot from it s center, Z = slot length, ρ_o and ρ_∞ = source and ambient densities.

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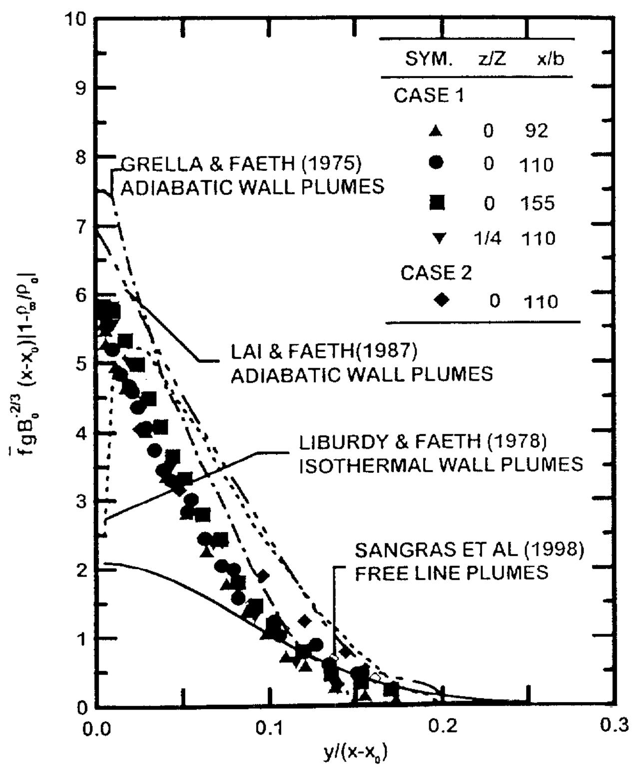

Fig. 1 Mean mixture fraction distributions in plane buoyant turbulent plumes.

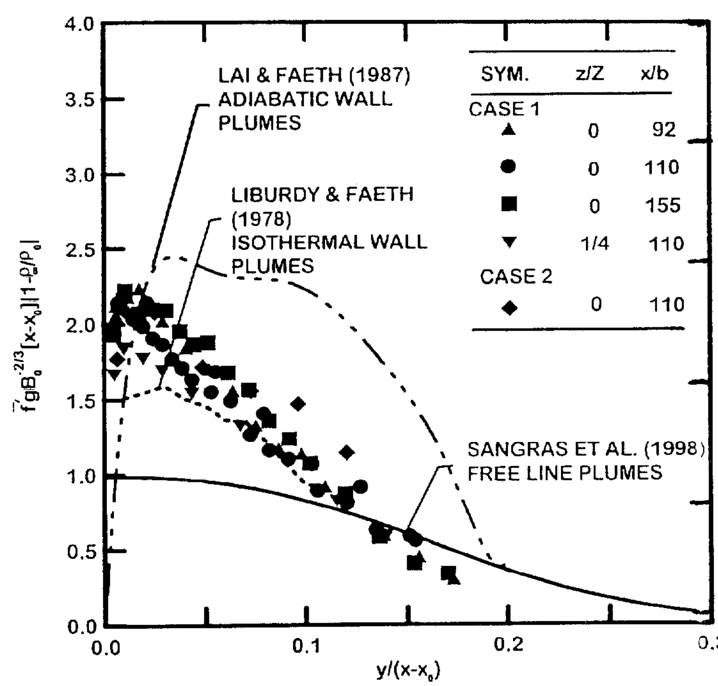

Fig. 2 Fluctuating mixture fraction distributions in plane buoyant turbulent plumes.