MASTER

SCALE EFFECTS IN LNG HAZARD ANALYSIS AND TESTING

Progress Report

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PROGRESS REPORT

The major effort of the contract year has been an extensive analysis of thermal radiation from unsteady diffusion flames, such as may be encountered in the burning of an LNG or LPG vapor cloud. The results of this analysis are reported in a paper, "Radiation from burning hydrocarbon clouds," by James A. Fay, Gary J. Desgroseilliers and David H. Lewis, Jr., which has been submitted for publication in Combustion Science and Technology. (The Abstract and Conclusion sections of this paper and appended to this report in lieu of a detailed discussion of the results).

This research provides a basis for determining thermal radiation from large-scale vapor cloud flames which burn in this manner. The use of a grey-gas model is shown to correlate the small scale data reasonably well. This model should be useful for analyzing radiation from large-scale, unsteady fires, in combination with the fluid mechanical and thermodynamic models which the paper describes.

A more detailed description of this research is contained in an M.S. thesis ("Radiation from Burning Hydrocarbon Clouds," Gary J. Desgroseilliers, M.I.T., August 1978).

The second principal effort has been the initiation of the development of an "intermediate level" fluid flow model to describe the behavior of vapor clouds and plumes released from LNG or LPG spills on land or water. This model is intermediate in the level of complexity between the very simplified gravity flow/dispersion models first used to describe vapor cloud dispersion and the more recent three dimensional,

unsteady finite-difference models which require extensive computational capacity.

The intermediate-level model which has been developed incorporates the usual assumption of a hydrostatic pressure distribution in the vertical direction. A vertical integration of the flow equation then reduces the spatial dependence to only the two horizontal dimensions. The resulting equations are hyperbolic, rather than elliptic, in nature. The flow external to the cloud or plume is assumed to be undisturbed. Dilution of the vapor cloud is provided for by entrainment of the external flow and by turbulent dispersion into the atmospheric boundary layer. Also, atmospheric shear stress is transmitted to the vapor layer. The movement of the edges of the cloud are described as an intrusive front, and hence are a boundary condition for the solution.

The first set of solutions which have been investigated are those for a one-dimensional steady flow from a line source of vapor which is heavier than air (such as LPG). (For simplicity, no heat transfer is considered, but this can be added as an additional complication). Attention has been focussed on the initial conditions and the asymptotic form of these solutions. In the cases so far investigated, gravity effects produce marked differences from the neutral buoyancy dispersion process.

For the remainder of the contract period, further work on the fluid flow model will be carried out. A major step will be the formulation of the one-dimensional unsteady and two-dimensional steady flow characteristic form of the equations of motion.

APPENDIX

Radiation from Burning Hydrocarbon Clouds

J.A. Fay, G.J. Desgroseilliers, and D.H. Lewis, Jr.

ABSTRACT

This paper reports on the measurement and analysis of time resolved thermal radiation from combustion of methane, ethane, and propane clouds; the vapor samples were initially contained within a soap bubble. The time scale of the radiant heat pulse was the same as that of the fluid mechanical motion (Fay and Lewis, 1976). The time integrated radiation, as a fraction of the initial fuel heating value, was between 0.09 and 0.15 for these fuels, with some dependence on initial fuel volume. The radiation was explained by a grey gas model, which assumed a uniform time dependent temperature in the spherical cloud and a time independent absorption coefficient. The grey gas temperature was found to decrease monotonically during and after the period of combustion. The absorption coefficient was found to be a function of the initial fuel volume, and fuel type; it was between 10^{-3} and 10^{-2} cm^{-1} and decreased slightly with increasing initial fuel volume.

CONCLUSIONS

The time integrated heat flux is a measure of the total thermal radiation from the fireball, and it can be expressed as a fraction of the fuel heating value. It was found that this fraction

was nearly independent of the initial fuel volume. For methane it averaged about 9% and decreased with increased fuel volume, was constant for ethane at 12%, and for propane it averaged about 15%, increasing with increased fuel volume. These results are consistent with measurements on steady flames.

The duration of the radiative pulse was found to scale with initial fuel volume as $g^{-1/2} V_f^{1/6}$, which is identical to the scaling law for visible flame height previously observed by Fay and Lewis (1976). Such a scaling law is consonant with the hypothesis that the fluid mechanical motion, which is dominated by gravitational forces, determines the duration of the evolution of the thermodynamic state of the reacting gas.

The observed radiation histories could be explained by a grey gas model which assumed uniform (but time dependent) temperature within a spherical gas cloud and a time independent absorption coefficient. In such a comparison, the fireball growth, which scaled in time according to the fluid mechanical scaling law, was empirically determined from observations of visible luminosity. When it was assumed that the absorption coefficient was independent of initial fuel volume, but had a value which reduced the grey gas temperature to a function of the dimensionless time only, the inferred temperatures were well below observed flame radiation temperatures in steady flames. This assumption was discarded as unrealistic. Instead, the absorption coefficient was determined as a function of initial fuel volume by requiring that the flame temperature at peak radiant intensity be the same as that measured

in steady flames. In this manner absorption coefficients in the range of 10^{-3} to 10^{-2} cm^{-1} were found, which decreased slightly with increasing initial fuel volume. We suggest that this volume dependence reflects the effect of initial volume on the duration of combustion which could influence carbon particle density in the flame.

For the period after combustion, when the fireball was cooling by adiabatic mixing with the surrounding air, the uniform temperature inferred from the grey gas model was compared with the thermodynamic temperature calculated from conserving energy in the product gases. The uniform temperature was generally greater than that calculated by the thermodynamic model, but the logarithmic rate of decay of the temperatures were nearly the same.

The observations of fireball growth, when compared with the fluid mechanical equations of motion, lead to the conclusion that, during most of the period of combustion, the average temperature in the fireball is declining. This is in agreement with the temperature histories inferred from the grey gas model.