TRANSIENT BEHAVIOUR OF DENSE GAS PLUMES

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I INTRODUCTION

The ultimate purpose of this study is to provide basic information on the structure of vapour plumes resulting from LNG spills on land for a realistic range of meteorological variables, source variables and site features. Small scale models of LNG tank-like complexes have been placed in a meteorological wind tunnel capable of simulating the appropriate meteorological conditions. Mean concentrations of dense vapour were determined by sampling concentrations of tracer gas (CO_2, cooled He-N_2 mixtures, or Freon 12-air mixtures) to simulate the LNG vapour. Initial measurements utilised a series of continuous release rates to interpret the effect of a variable boiloff rate field condition (Meroney *et al* (1976, 1977) and Neff *et al* (1976)).

The current program includes measurements of transient boiloff release rates with fast response anemometers and the validation of the modelling criteria.

II LABORATORY SIMULATION OF CRYOGENIC SPILLS

The reliability of the use of wind tunnel shear layers for modelling atmospheric flows has been demonstrated by several investigators (Cermak, 1975). Specific problems associated with the dispersion of cold natural gas plumes have been previously discussed by Meroney *et al* (1976). The Froude number is the primary parameter which governs plume spread rate, trajectory, plume size and entrainment when gases remain negatively buoyant during their entire trajectory. Earlier measurements (Neff *et al* (1976) and Meroney *et al* (1977)) suggest that heat transfer effects may be small over the significant time scales; hence gas density should be adequately simulated by isothermal high molecular weight gas mixtures. Visualization of similar tests for the range of model scales used (1:130 to 1:666) indicate a similar plume geometry. Concentration results of the different model scales agreed to within the experimental accuracy of approximately ±20%. Similarly, identical tests also show good agreement; hence the Reynolds number must play a minor part in the dense gas dispersion situations considered.

III WIND TUNNEL EXPERIMENT

Scale models (1:200 and 1:400) of two typical LNG storage tanks have been studied in the meteorological wind tunnel for a neutral and stable atmosphere.

Tank facilities considered include a low dike configuration (39 m diameter tank, 36 m high surrounded by a 6.6 m high dike 93 m by 100 m in area) and high dike configuration (73 m diameter, 39 m high tank surrounded by a concentric 81 m diameter dike 24 m high). Also examined was a 1:106 scale model of Test 044 from the Capistrano Series supported by the American Gas Association (1974) which involved a spill into a 25 meter diameter by 0.5 meter high dike.

All results presented herein are modelled with pure Carbon dioxide or pre-cooled Helium-Nitrogen mixtures adjusted to simulate boiloff densities of methane. Turbulent diffusion of simulated LNG plumes for the three different LNG tank and dike complexes, two model gas mixtures, two atmospheric stratifications, three scale ratios, and a number of wind speed and boiloff rate combinations were studied. Mean concentration measurements were obtained for as many as 23 different sample points distributed over a ground level zone up to 250 m wide, 50 to 2000 meters long, and in the vertical over a height of 0 to 100 meters. A schematic of the model configuration and the associated concentration measuring equipment is shown in Figure 1.

To obtain an accurate prediction of the extent of hazard associated with the vapourization of LNG, the model should simulate the variable boiloff rate of the gaseous methane characteristic to that of the spill configuration. Typical boiloff curves for the prototype situation along with the actual model gas release for the Capistrano Test 044 are presented in Figure 2. These gas flow rate curves were obtained by use of a programmed cam to close a micrometer needle valve controlling the flow of simulation gas at a predetermined rate.

The transient nature of the boiloff rates simulated necessitated the use of a fast response, temperature compensated concentration transducer. An aspirated dual film probe was designed for this project. As noted in Figure 3, dual films operated at different current levels permitted compensation for temperature drift, while a flared inlet reduced the noise of pressure fluctuations. Calibration suggests a noise level of 0.1% by volume CO_2 and an upper frequency response of 1000 Hz.

IV TEST PROGRAM RESULTS

Test results consisted of (1) a qualitative study of the flow field arou[illegible] the different tank and dike localities by visual observation of the plume released from the model area; and (2) a quantitative study of gas concentrations produced by the release of a tracer from the model area.

1. Continuous Boiloff Release Results

Continuous releases of CO_2 made from the high and low tank-dike configurations agree well with the earlier Freon-12-N_2 simulations performed by Neff *et al* (1976). The dimensionless concentration coefficient $\chi \bar{U} H_T^2/Q$ scales with non-dimensional downwind distance x/H_T (Figure 4). The dimensionless concentration coefficient curves asymptotically approach the slope of those given by the appropriate Pasquill diffusion category for both neutral and stable flow. No significant differentiation appeared between CO_2 and pre-cooled HeN_2 simulation gases.

2. Variable Boiloff Release Results

Figure 5 displays the dilution time history of the Capistrano Model Test and the field situation superimposed for the typical test position (320', 0', 0'). The time and magnitude of highest concentrations observed at most of the test locations is in good agreement. The arrival time of the transient plume at the measurement location is reasonably close. The model does not, however, predict the large and intermittent concentration peaks at late times as observed in the field. Such variations are likely due to gustiness and changes of wind direction recorded for the field case but not present in the wind tunnel.

Transient measurements made downwind of the typical high and low dike configurations reveal that mean concentration measurements made at constant boiloff rates appear to upper bound conditions to the maximum concentrations detected during a transient boiloff situation.

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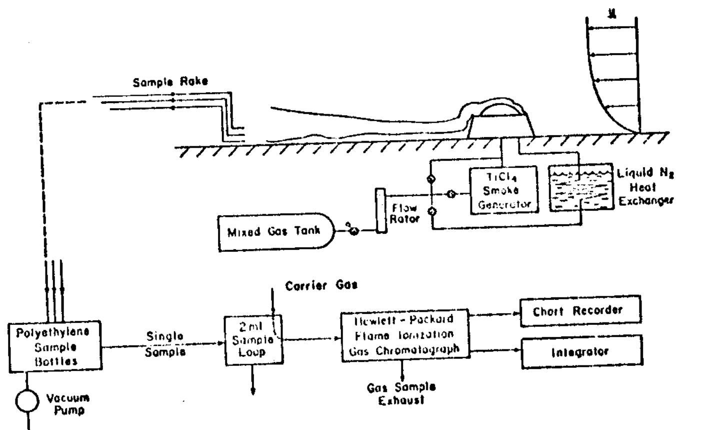

Figure 1: Block Diagram of Gas-Mixture Release System and Mean Concentration Sampling System.

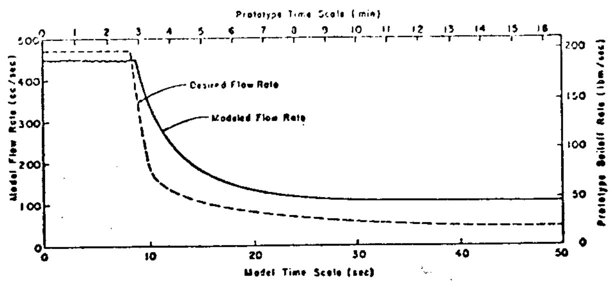

Figure 2: Capistrano 044 Gas Release Rates for Model and Prototype.

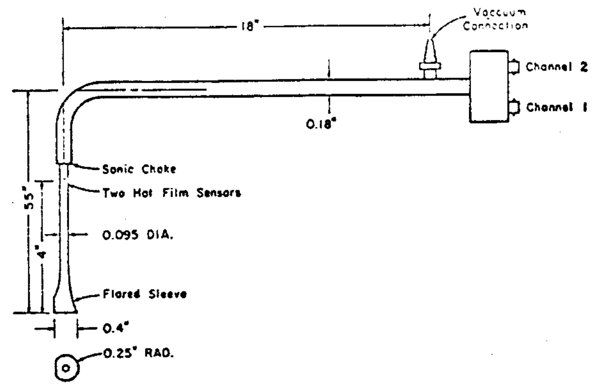

Figure 3: Temperature Compensated Aspirated Dual Hot Film Probe

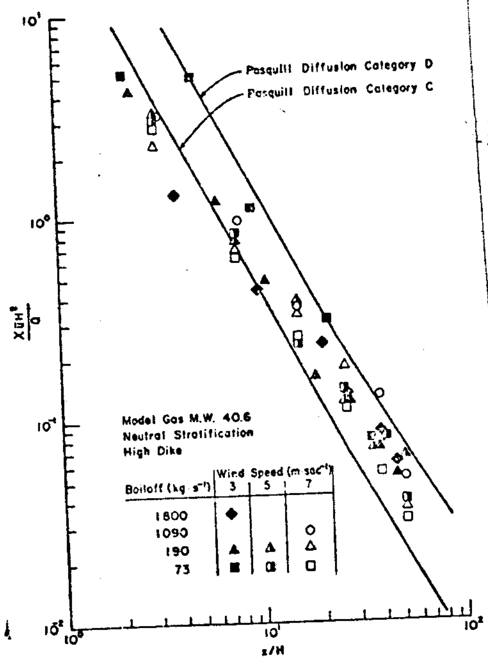

Figure 4: Dimensionless Concentration Coefficient vs Downwind Distance, Constant Boiloff Rate.

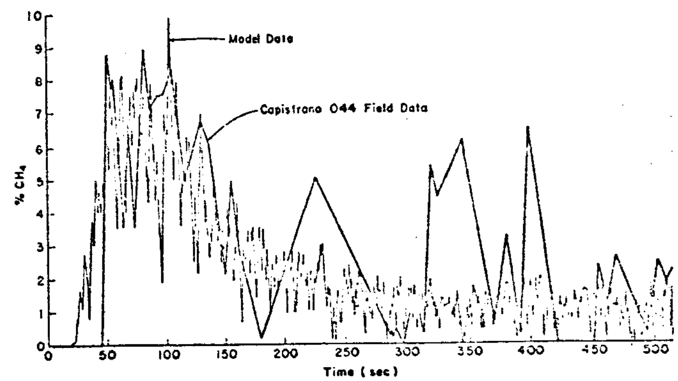

Figure 5: Comparison of Model Data with Capistrano 044 Field Data for a Sample Location at (320', 0', 0').