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DESIGN OF THE THORNEY ISLAND CONTINUOUS RELEASE TRIALS

J. McQUAID

Research and Laboratory Services Division, Health and Safety Executive, Broad Lane, Sheffield S3 7HQ (Great Britain)

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Summary

The Heavy Gas Dispersion Trials project at Thorney Island primarily consisted of field experiments on the dispersion of fixed-volume clouds. As a sequel to the main series, the release configuration was modified to permit a study of steady, continuous releases and 3 trials were performed. This paper describes the objectives and design of the trials, summarises the results obtained and discusses some noteworthy features.

1. Introduction

The Heavy Gas Dispersion Trials (HGDT) project was set up specifically to study the dispersion of fixed-volume releases of heavy gas. The programme was extended to include a series of trials on steady, continuous plumes. The design of the fixed-volume trials, the trials' site and the instrumentation have been described previously [1] and more fully in McQuaid and Roebuck [2]. This paper is concerned with the continuous release trials and completes the description of the programme. Several analyses of the data are given elsewhere in this volume.

By way of brief background, the continuous-release trials became possible as a result of the sale of the instrumentation to the trials' contractor (the National Maritime Institute) and the conversion of the gas container to provide a steady flow rate needed for a separate series of trials arranged with the U.S. Department of Transportation. Thus the design of the continuous-release trials was constrained by the existing inventory of instrumentation, the data handling capacity and the limitation on gas supply rate. The programme was not intended to be a comprehensive investigation. Nonetheless, the ad hoc arrangements, which should be seen as a bonus on the main programme, were successful and valuable results were obtained.

2. Objectives of the trials

The broad objective was the same as for the fixed-volume trials, i.e. to obtain reliable data for the validation of physical and mathematical models of heavy gas dispersion. The design configuration was intended to provide, as far as possible, a further idealised release condition which, with the fixed-volume results, would bracket the transient release condition typical of many accidental release situations. The prime considerations were therefore that the release rate

— should give a plume which would result in measurable concentrations over the instrumented range and thus make maximum use of the fixed array of instruments, and,
— should be capable of being maintained for a duration which would allow meaningful time-average concentrations to be derived.

The detailed definition of equipment to meet these objectives would of course have required a prejudgement of the results of the trials but this was the same situation as prevailed at the time of the design of the fixed-volume trials. Model predictions were used to aid the judgement. The first condition dictated a low windspeed whilst, for the second, flexibility was limited due to the constraints already mentioned.

In view of the very limited programme that could be mounted, the trials were confined to dispersion over flat ground.

3. Design of the trials

3.1 The existing system

The trials were performed on the same site and with the same types of instrumentation and data handling arrangements as described by McQuaid [1]. The gas delivery system consisted of a fan and ducting connected to the base of the 2000 m^3 gas container used for the fixed-volume trials. The fan extracted the gas at a rate of about 5 m^3/s and it was then ducted below ground to the chosen release position. In a trial, the gas container was filled with a mixture of refrigerant-12 and nitrogen in the same way as for the fixed-volume trials. The smoke marking of the gas was achieved in the delivery duct by successive firing of smoke grenades.

3.2. Selection of design parameters

3.2.1 Geometry and location of the source

The source was designed to give a ground-level release with zero vertical momentum. The design is shown in Fig. 1. The diameter of the cap and its height above ground level were such that the horizontal outflow velocity fell below the gravity-spreading velocity at a radius within the periphery. The source

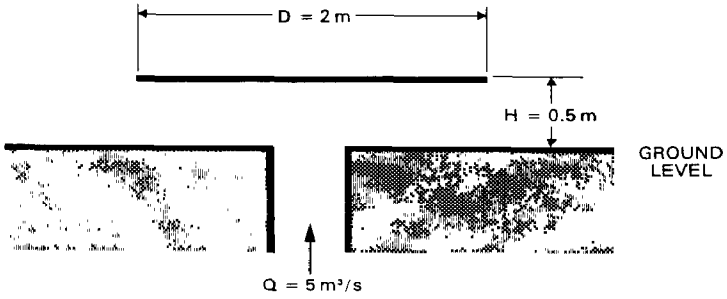

Fig. 1. The geometry of the gas source.

was located at 50 m to one side of the gas container (i.e. at about 3.5 container diameters) transverse to the axis of the final array of instrumented masts. The choice was a compromise between the need to ensure that the plume avoided the wake of the container as far as possible and the need to make maximum use of the existing instrument array.

3.2.2 Release rate and duration

These were fixed by the system already installed at the site. The rate was about 5 m^3/s and could be maintained at this value for about 400 s. A gas sensor was placed at the periphery of the source and the record from it provided the start time of the release. The record also served to indicate the end of the release, supplemented by information from two other indicators. The first was the gas sensor in the container at 0.4 m height and the second was a dynamic pressure transducer at the fan inlet which recorded a fall in pressure as the density changed. With these three indications, it was possible to fix the end of the release to better than 10 s. The values of the release rate in the trials were derived from the estimates of the volume of gas in the container and the duration of the trials.

3.2.3 Atmospheric conditions

Predictions of plume development were obtained using the CRUNCH code [3]. The predictions showed that the distance to the 0.1% concentration, at the design release rate and a windspeed of 2 m/s, was about 300 m from the source in Pasquill category D stability and about 500 m in category F stability. These distances were well-matched to the layout of the instrument array and the lower limit of resolution of the gas sensors. The design intention was therefore accepted as a windspeed of around 2 m/s with no restriction on the stability category.

3.2.4 Initial relative density ratio

This was fixed at about 2.0 as had been the case for most of the fixed-volume trials.

TABLE 1

Summary description of continuous release trials

Trial number	Wind speed[a] (m/s)	Pasquill stability category[b]	Release rate (m^3/s)	Initial relative density ratio	Number of gas sensors which detected gas	Number of sonic anemometers in the plume[c]
045	2.1	E/F	4.3	2.0	88	3
046	3.2	D	4.3	2.0	25	1
047	1.5	F	4.2	2.05	82	4

[a]Wind speeds are at 10 m height and averaged over the duration of the trials.
[b]Pasquill stability categories were assessed from observation, solar radiation, vertical temperature gradient, standard deviation of horizontal wind direction and Richardson number.
[c]Plume extent defined by records from gas sensors.

3.2.5 Layout of instrumentation

The location of the gas source off the axis of the existing instrument array required a redisposition of instruments to restore some balance to the layout. The 30 m weather mast used in the earlier trials had suffered storm damage and was replaced by a 20 m mast for the continuous release trials. Full details of the instrumentation layout are given in McQuaid and Roebuck [2].

4. The trials performed

The plan envisaged two trials but in the event three were performed. In one of the trials, the coverage of the instrument array by the plume was limited due to a large deviation of the wind direction from the array axis.

A summary description of each trial is given in Table 1. The windspeeds and release conditions were all close to the specification. Satisfactory coverage was achieved by the instrument array, as indicated by the numbers of gas sensors and sonic anemometers in the plume, with the exception of the trial noted above (see Table 1).

The plume in each of the trials was characteristically very shallow and wide. The visible depth was no more than about 2 m over much of the plume's extent and the visible width was as much as 300 m.

Puttock et al. [4] classified field trials on dense gas dispersion according to the extent to which 'dense gas' effects influenced the trials. The measure they used for continuous releases was the value of the initial Richardson number defined as

$$Ri_0 = \frac{g'_0 H_0}{U_*^2}$$

where g'_0 is the reduced gravitational acceleration corresponding to the initial

TABLE 2

Comparison of initial Richardson numbers

Source	Programme	Ri_0
Puttock et al. [4]	Bureau of Mines	10–200
	Maplin Sands - Propane	600
	Maplin Sands - LNG	40
	China Lake - Burro	25
Koopman et al. [5]	Desert Tortoise	90–200
	Thorney Island - 045	380
	- 046	160
	- 047	740

density difference, H_0 is the initial height of the plume and U_* is the friction velocity. Table 2 compares the results quoted by Puttock et al. with values calculated for the Thorney Island trials. Also included are values estimated for the Desert Tortoise ammonia spills reported by Koopman et al. [5]. The comparison in Table 2 shows that Trial 047 in the present series has the largest Ri_0 of all the continuous release trials so far conducted.

5. The results of the trials

The presentation of results in this paper is limited to consideration of the primary records from the trials. Comparisons will not be made with the predictions of mathematical models nor will processed results be considered. Results of such studies are included elsewhere in this volume [6,7].

Although the conditions in Trials 045 and 047 were very similar, the ground plan of the plumes in the two trials displayed noticeable differences. The lateral spread, especially in the near field, was less in Trial 045 than in 047 and this is consistent with the respective windspeeds of 2.1 m/s and 1.5 m/s. The greater spread in Trial 047 may be due in part to a significant variation (of around 20°) in wind direction over the duration of the trial. The downwind extent of the plume (i.e. the distance to 0.1% concentration) was greater in Trial 045 than in 047 at the lower windspeed. There is no unanimity amongst modellers as to the way this distance should vary with windspeed. The result quoted above is unambiguous and is fully supported by the results for distances to higher concentrations. It cannot be explained by the variations in windspeed about the quoted averages. There was little or no trend in windspeed in the case of 045 and there was a marked downward trend in the case of 047.

The principal result of importance, from the point of view of mathematical modelling, is the distribution in space of the constant or steady-state concentration. The confirmity to a steady-state at a receptor depends on the duration

of release and the advection time from the release point to the receptor, which determines the extent to which longitudinal spreading and dispersion smear out the leading and trailing fronts of the plume. The limited duration of the releases was such that isolated plumes were obtained within the measurement field, i.e. the source flow had ceased at about the time that the plume front reached the furthest sensor. Thus the downwind distance over which a steady-state condition prevailed (which of course depends on the averaging time accepted) was rather less than the full measurement range. Some of the gas sensor records at positions along (or close to) the mean wind direction in Trial 045 illustrate the degree to which steady-state conditions were attained. The records are shown in Figs. 2a–2c and illustrate a progression from a steady-state extending over approximately 350 s at 36 m to an absence of any steady-state at 250 m. Similar results are exhibited by the records from Trials 046 and 047. These results are in very marked contrast to experience in field trials conducted by the Lawrence Livermore National Laboratory [5]. They obtained a much greater (by a factor of around 10) duration of a steady-state condition relative to the duration of release at particular distances and windspeeds than exhibited in these trials. This difference is of obvious importance to mathematical modelling and requires further investigation.

The records of concentration at different heights and downwind distances illustrate a number of effects. In the near field, although the rise of concentration corresponding to arrival of the plume was very sharp, there was an extremely slow decay after the release has ceased. This decay period was typically as long as the release time and reflected the slow clearance of gas trapped in and near the grass surface, an effect noticed previously in the fixed-volume trials.

The concentration records in the near field also confirm the visual evidence of the shallow depth of the plume. The sensors at a height of 1.4 m displayed an intermittent signal, i.e. there were prolonged periods when no gas was detected at this height. This is well illustrated in Fig. 3 which shows the 1.4 m gas sensor record at a distance of 36 m from the release point in Trial 047. The top surface of the plume had the appearance of a sharp interface, with little visual evidence of the vigorous mixing motions characteristic of passive plumes. The peak concentration in Fig. 3 is no more than about 1/20th of that at the 0.4 m sensor on the same mast. This large vertical gradient of concentration at near-field positions means that it would not be appropriate to take the 0.4 m sensor as being at 'ground' level, as was generally done in the fixed-volume trials.

In the far field (i.e. at more than about 250 m from the release point) there is clear evidence that the gas arrived at the upper sensors before being detected at the lowest level. Furthermore, the peak concentration at the lowest level occurred at a time well after the main body of the plume had passed the sensors at the higher levels. These results again suggest that hold-up of the gas in the

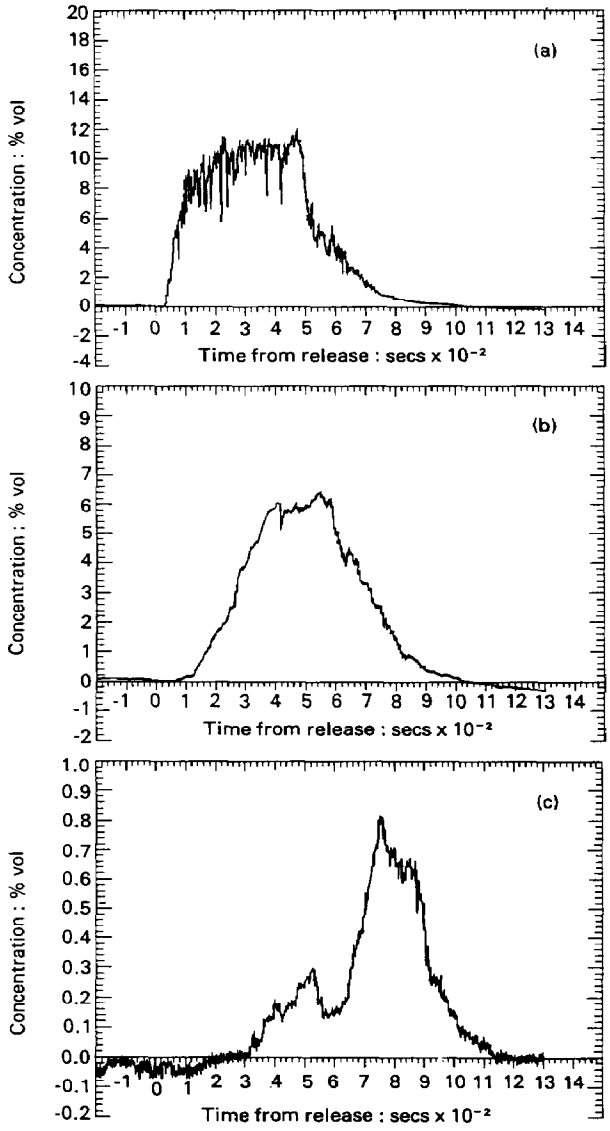

Fig. 2. Gas concentration versus time records at a height of 0.4 m from Trial 045 at positions on, or close to, the axis of the plume: (a) 36 m from the source at location (428, 228); (b) 90 m from the source at location (400, 275); and (c) 250 m from the source at location (300, 400).

grass surface was a significant factor in the experiments. (The grass was typically 0.3 m high, a significant fraction of the plume depth.)

The trials' data include several records from sonic anemometers within the plume. The records show marked reductions in turbulence intensities over the duration of plume passage. Analysis of these data is given in Mercer and Davies [7].

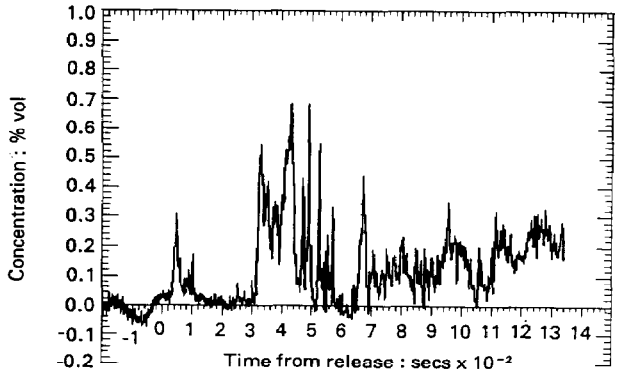

Fig. 3. Gas concentration versus time record at a height of 1.4 m from Trial 047 at 36 m from the source (location 428, 228).

6. Concluding remarks

Large-scale trials on the dispersion of continuous releases of heavy gas generally adopt a steady-state spill of liquified gas as the source flow. The rate of evolution of gas in that type of experiment is time dependent, complicating the comparison of results with predictive models. The steady gas release in the source flow of the present trials results in a body of data that should be particularly useful for validating mathematical models. Furthermore, the source arrangement is well-suited to simulation in wind or water tunnels. Although of limited scope, the programme has provided valuable additional information on heavy gas dispersion at large scale.

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