Journal of Hazardous Materials, 11 (1985) 417—423
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

IMPROVED UNDERSTANDING OF HEAVY GAS DISPERSION DUE TO THE ANALYSIS OF THE THORNEY ISLAND TRIALS DATA

SYLVIUS HARTWIG

Universität Wuppertal, 5600 Wuppertal 1 (F.R.G.)

(Received June 4, 1984; accepted December 6, 1984)

Summary

The large amount of experimental data produced by the Thorney Island trials will take some years to evaluate. In this paper, some preliminary conclusions are drawn regarding several features of heavy gas dispersion as exhibited by the data in clarifying the different views of modellers on the specification of the turbulent diffusivities in the cloud.

1. Introduction

As a result of the Thorney Island trials, a large amount of experimental data has become available for analysis. It will take another two or three years before the groups concerned with the trials will have evaluated the major part of these data, will have drawn their conclusions, and will have published the results.

In this paper, some preliminary conclusions are discussed regarding the improvements in understanding of the dispersion of heavy gas clouds resulting from the analysis of the data performed to date. The discussion is restricted to the results of the Phase I trials. The details of the data analysis and evaluation of the physical parameters on which the discussion is based are presented elsewhere [1].

For the time being, only some points can be touched upon very briefly. First those areas which show signs of improved understanding will be discussed, and second an area where some improvement will be expected in the future will be highlighted.

2. The problem of diffusion

In the mid-1970s the view that heavy vapour clouds show only small vertical diffusion or "Austausch" became generally accepted, whereas in previous years it was assumed that the dispersion of heavy vapour clouds was similar to the dispersion of tracers. This small "Austausch" can be considered with-

0304-3894/85/$03.30

in integral dispersion models by parameters (for instance entrainment) which are chosen *ad hoc* and which are drawn from general experimental experience and consideration. As regards differential models (the so-called numerical models), physically more plausible assumptions may be made. In such models the turbulent diffusion has almost exclusively been described by the K-coefficients approach (K-models) up to now [2—4]. In this connection a coefficient of turbulent diffusion [5], brought about by wind fluctuation, is introduced similar to molecular diffusion in the Navier—Stokes equations. Various modellers have so far assumed that there is clearly less turbulent diffusion in a heavy vapour cloud than in the atmospheric boundary layer. However, this hypothesis could not be confirmed by differential experimental data, but was simply concluded from the integral behavior of the heavy vapour cloud. The first results of the evaluation of the Thorney Island trials [1] suggest that the turbulent "Austausch" within a vapour cloud is smaller by almost one order of magnitude. Figures 1 and 2 show the diffusion coefficients of two trials, as they were calculated for different phases of a spreading cloud. The calculation provides the average values of the vertical diffu-

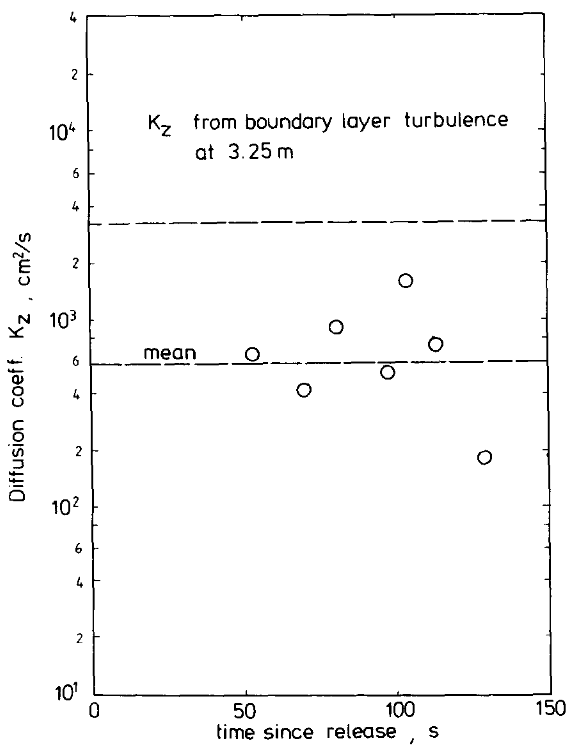

Fig. 1. Eddy diffusion coefficient K_z (cm²/s) calculated from concentration gradient of front of vapour cloud for different phases of dispersing cloud (Trial 7). Time refers to duration since release. Lower dashed line gives mean value of K_z. Upper dashed line gives calculated value of K_z at 3.25 m height of undisturbed boundary layer.

sion coefficient in the cloud from consideration of the changing concentration profile; details are provided in [1]. As a comparison, the K-coefficient for the undisturbed boundary layer is indicated as well. This has been derived from the relationship of Wu [6] for K_z in terms of the velocity and temperature gradients (see [1]).

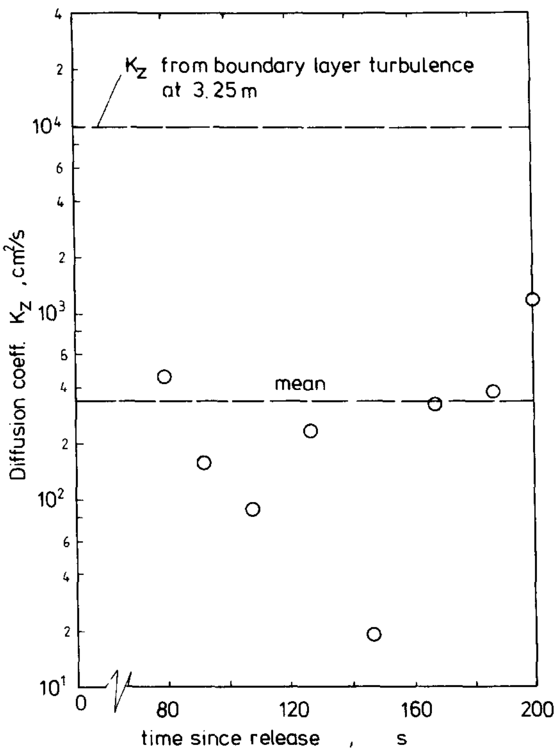

Fig. 2. Same as Fig. 1 but for Trial 8.

3. Integral dispersion modelling and energy and momentum conservation

The first attempts of modelling gravity spreading go back to van Ulden [7]. Generally speaking, in these models the spreading velocity of the vapour cloud is calculated from the kinetic energy, and this in turn is deduced from the potential energy of the heavy gas cloud. In these models the entire potential energy and the kinetic energy are related right from the beginning. As a consequence, the heavy vapour cloud has its maximum gravity velocity at the moment of release, which then gradually decreases. From a physical point of view this conception is of course untenable, since the heavy vapour cloud has its own inertia and has to be accelerated from a zero velocity. Thus, the modelling of the gravity spreading should be reconsidered as regards the initial spreading phase [8], because evaluations of the trials show that initially the heavy gas really runs through an acceleration phase [7]. This is shown in Fig. 3, where the experimental curve has been calculated from the results in [9].

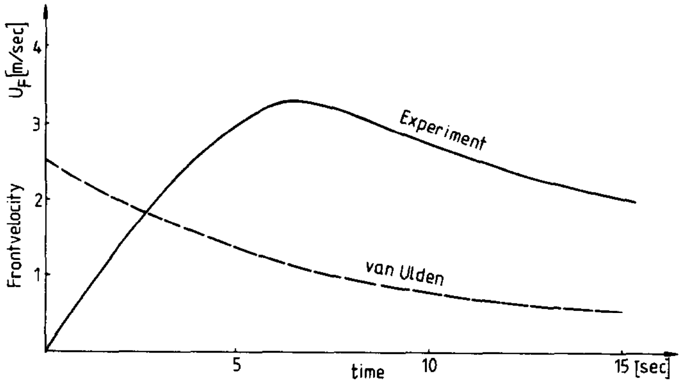

Fig. 3. Front velocity over time calculated with van Ulden's model (dashed line) and inferred from Thorney Islands trials (Trials 7, 8, 9, 11, 14).

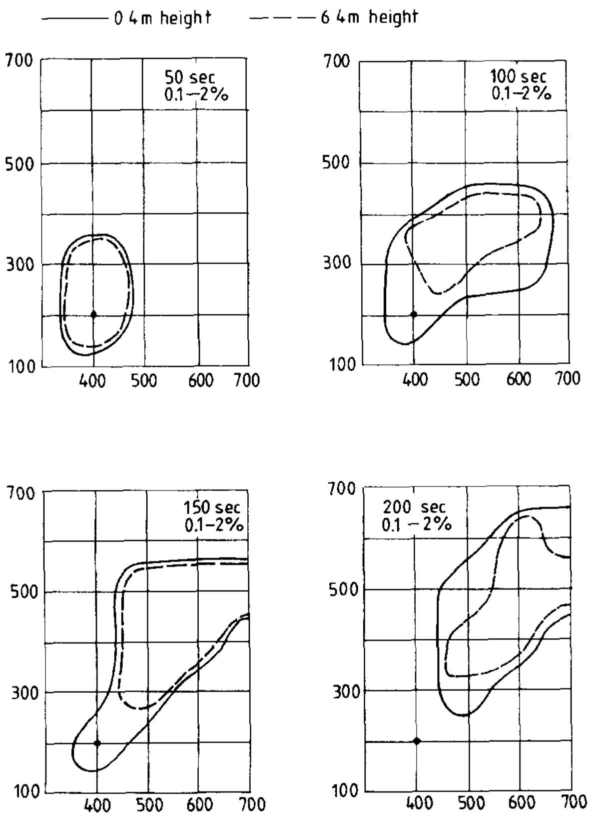

Fig. 4. Area of vapour cloud at 0.4 m and 6.4 m height in which sensors showed relative concentration greater than 0.1 for 50 s, 100 s, 150 s and 200 s time after release (Trial 007).

4. Purpose of large-scale instantaneous releases

During the planning phase of Thorney Island trials the purpose of these trials was often discussed between the different types of sponsors. One group held the opinion that the main task consisted of research into basic physical features, whereas others were mainly interested in industry-oriented safety data, as for example safety zones and distance.

There is no doubt that general considerations about the drift of the cloud and estimation of the cloud-covered area lead to the conclusion that concentration values higher than the lower flammability limit may occur at large

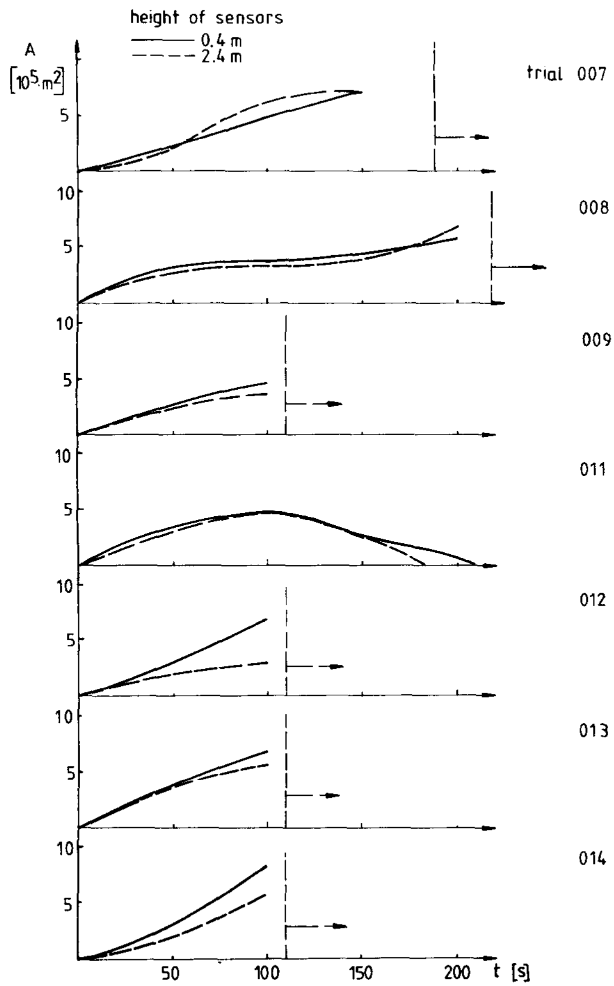

Fig. 5. Area of vapour cloud vs. time after release for Trial 007 to Trial 014 as determined from gas sensors in units of 10^5 m^2. Time when cloud leaves the sensor field is given by vertical dashed lines.

distance from the release point. Nevertheless it is confirmed by the experiments that even large sensor fields within which large-scale trials are carried out do not enable for example, the examination of safety zones, because parts of the cloud or the entire cloud (still at hazardous concentration levels) drift away from the test area, so that no further measurements are possible.

Figure 4, for example, shows the contours of a heavy vapour cloud as a function of time at heights of 0.4 and 6.4 m, respectively. Figure 5 shows the time-dependent area covered by the vapour cloud of 6 different trials as well as the point of time at which part of the heavy vapour cloud leaves the sensor fields. In 6 out of 7 cases the cloud area is still in the growth phase when spreading beyond the sensor field. Thus theoretical considerations have to be used to evaluate safety distances.

5. Boundary layer between vapour cloud and atmosphere

Some theories assume that the turbulent diffusion is at the same low level everywhere within a vapour cloud [3]; another assumption is that the "Austausch" at the boundary layer cloud—atmosphere is significantly smaller than inside the cloud [1]. Figure 6 shows this hypothesis, which is of fundamental importance for the modelling of heavy gas dispersion. Up to now, turbulence data do not enable a decision between the two different K-modelling approaches but the author hopes that the Thorney Island trials data will be detailed enough to make a decision between these two hypotheses.

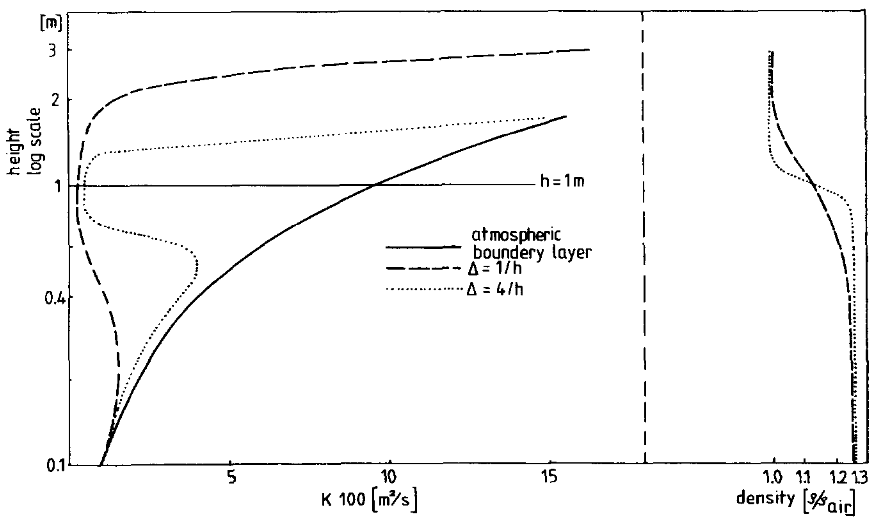

Fig. 6. Eddy diffusion coefficient for different relative density (diagram on right hand side) in dependence of height [4]. Low values of coefficient for boundary layer between cloud and atmosphere are clearly shown (dashed lines). The solid line gives values for an undisturbed atmospheric boundary layer. K: eddy diffusion coefficient; h: height of vapour cloud; Δ: the extent of transition area where density of cloud falls to density of air.

Acknowledgement

The author is grateful to Dr. W. Heudorfer and Mr. G. Schnatz for inspiring discussions.

References

1 S. Hartwig, G. Schnatz and W. Heudorfer, Improved understanding of heavy gas dispersion and its modelling, in: G. Ooms and H. Tennekes (Eds.), Proc. IUTAM Symposium on Atmospheric Dispersion of Heavy Gases and Small Particles, August 29—September 2, 1983, Delft University of Technology, Springer-Verlag, Berlin, 1984.
2 J.A. Havens, A description and assessment of the Sigmet LNG vapor dispersion model, Report No. CG-M-3-79 for the US DOT and United States Coast Guard, 1979.
3 S.T. Chan,, FEM 3 — A Finite Element Model for the Simulation of Heavy Gas Dispersion and Incompressible Flow: User's Manual, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53397, 1983.
4 G. Schnatz and D. Flothmann, A K-model and its modification for the dispersion of heavy gases, in: S. Hartwig (Ed.), Proc. Symposium "Heavy Gas and Risk Assessment", D. Reidel, Dordrecht, 1980.
5 S. Hartwig, Identification of problem areas related to the dispersion of heavy gases, von Karman Institute Lecture Series, 1982, vol. 3, Brussel, 1982.
6 S.S. Wu, A study of heat transfer coefficients, J. Geophys. Res., 70 (1965) 1801—1807.
7 A.P. van Ulden, On the spreading of a heavy gas released near the ground, in: C.H. Buschman (Ed.), Loss Prevention and Safety Promotion in the Process Industries, Proc. 1st Int. Symposium on Loss Prevention and Safety Promotion in the Process Industries, Delft, The Netherlands, 1974, Elsevier, Amsterdam, 1974, pp. 221—226.
8 A.J. Prince, P.W.M. Brighton and D.M. Webber, Thorney Island Heavy Gas Dispersion Trials — determination of path and area of cloud from photographs, Report SRD R 318, Safety and Reliability Directorate, UKAEA, Culcheth, 1984.
9 G. Schnatz, J. Kirsch and W. Heudorfer, Investigation of energy fluxes in heavy gas dispersion, in: S. Hartwig (Ed.), Proc. Symposium "Heavy Gas and Risk Assessment II", D. Reidel, Dordrecht, 1983.