Journal of Hazardous Materials, 11 (1985) 409—416
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

SOME FINDINGS BASED ON WIND TUNNEL SIMULATION AND MODEL CALCULATIONS OF THORNEY ISLAND TRIAL No. 008

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(Received May 18, 1984; accepted October 8, 1984)

Summary

In this paper some comparative experimental results and model calculations of Thorney Island trial No. 008 are presented. Furthermore the wind tunnel simulation of the Phase I Thorney Island trials is discussed and an example of trial No. 008 is shown. Conclusions are drawn from a comparison of the results, and future plans for further investigation of heavy gas dispersion characteristics are presented.

1. Introduction

The importance of understanding the behaviour of heavier-than-air gas clouds is acknowledged in the field of risk assessment. In risk analyses or safety studies, the spreading and dispersion of an accidental heavy gas release is usually calculated making use of a theoretical heavy gas dispersion model. There is still little proof of the degree of accuracy of dispersion models.

TNO's Division of Technology for Society therefore sponsored the HGDT-project in order to achieve a better understanding of heavy gas dispersion and to improve and verify our theoretical and wind tunnel models.

TNO's Division of Technology for Society is involved in the field of heavy gas dispersion by developing and applying models on a theoretical base to calculate cloud behaviour as part of effect-and-consequence calculations in risk analyses. Furthermore wind tunnel simulation is being used as a tool to get a more precise understanding of cloud behaviour in complex situations.

In this paper some results are presented of a first analysis of both theoretical and wind tunnel modelling, applied to the results of field test No. 008 of Phase I of the HGDT at Thorney Island [1].

2. Description of trial No. 008

Trial No. 008 was carried out on September 9, 1982 at a neutral stability condition (Pasquill class D) and a (low) wind speed of 2.4 m/s at 10 m height.

0304-3984/85/$03.30

Relative density of the Freon-12/nitrogen mixture in the gas bag was 1.63.

The bulk Richardson number or modified Froude number is defined as

$$Ri = \frac{\Delta\rho}{\rho_a} g \frac{H}{U_{10}^2} \tag{1}$$

with $\Delta\rho = \rho - \rho_a$, ρ = initial gas density in kg m^{-3}, ρ_a = air density in kg m^{-3}, g = gravitational constant in m s^{-2}, H = initial cloud height in m, U_{10} = wind speed in m s^{-1} at 10 m height. It is a measure of the dense gas effect. In this trial the bulk Richardson number was approximately 15. This is in fact a very high value and therefore striking density effects are visible in the photographic and video recordings of the experiment. In trial No. 017, a pure Freon release, the bulk Richardson number was approximately 13. One would expect nearly the same slumping behaviour on a different time scale.

The gas sensor readings from trial No. 008 used in the comparisons were those at the locations listed in Table 1. The coordinate system has been rotated so that the x direction in aligned with the mean wind direction.

TABLE 1

Coordinates of eight usable gas sensor readings

Trace No.[a]	x	y	z
G04	34.2	62.1	0.4
G12	96.3	26.7	0.4
G30	191.5	53.5	0.4
G02	62.1	34.2	0.4
G08	123.1	68.5	0.4
G21	144.4	40.7	0.4
G13	96.3	26.7	2.4
G03	62.1	34.3	2.4

x: distance from source in wind direction in m.
y: distance perpendicular to wind direction in m.
z: height above ground level in m.
[a]Numbering system in data record for trial No. 008 [1].

3. Wind tunnel simulation

For the wind tunnel simulation of the field trials a release system was built, consisting of two parts. The main part is a piece of PVC piping of diameter 0.13 m, which is retractable in the floor of the tunnel. The top of the tube is closed with a lid which is removed just before each experiment by simply pulling a string. The length scale ratio is 1 : 107. Mixing in this "gas bag" is achieved by continuously pumping gas into the bag where the surplus is drained by way of an overflow tube in the top of the bag. The wind tunnel is an open-end type atmospheric boundary layer tunnel. Crosssection dimensions are a width of 2.65 m and height of 1.2 m. The test section is 6.8 m long. A full description of the boundary layer simulation is given in [2].

Full-scale wind speed in trial No. 008 was 2.4 m/s at 10 m height. Froude number ($U/\sqrt{gH}$) scaling with a 1 : 107 length ratio would lead to a model scale windspeed of 0.23 m/s. Such a low wind speed causes technical problems to maintain a stationary and well-defined boundary layer in the wind tunnel. Therefore we applied bulk Richardson number scaling which means that

$$Ri = g \frac{\Delta\rho}{\rho_a} \frac{H}{U_{10}^2} \tag{2}$$

is scaled instead of both density difference ratio ($\Delta\rho/\rho_a$) and Froude number separately. By increasing the density difference ratio a more practical wind tunnel speed results. By using pure Freon-12 the following scaled properties result:

gas bag diameter	= 0.13 m
density difference ratio, $\Delta\rho/\rho_a$	= 3.163
model windspeed	= 0.53 m/s
time scale	= 1 : 23.7

From the upwind windspeed measurements in the field as a function of height we derived a roughness length z_0 of only 0.003 m. Simulated roughness length in the wind tunnel during the experiments was 0.006 m, achieved through carpet covering of the tunnel floor.

Flow visualization experiments recorded on video tape* show similar overall cloud behaviour in the field and in the wind tunnel. Concentration measurements were made with five catharometers (plus one reference channel) simultaneously through a data-logger system with 4 Hz sampling frequency per channel. Scaling up to full-scale sampling rate one measured value per approximately 6 s is available. A total of approximately 700 measurements were carried out. Each measurement was repeated at the same position and all measuring positions were chosen symmetrically around the wind direction. Assuming symmetric behaviour of the cloud in positive and negative y-direction results in 175 sets of four concentration traces spread over three heights: z = 0.4 m, z = 2.4 m and z = 4.4 m. This set contains the positions listed in Table 1 which will be considered further.

4. Dispersion calculation model

For the calculation of the dispersion of heavier-than-air gases a standard TNO heavy gas dispersion model [3] was used. This is a relatively simple

*An edited video tape can be made available on request.

integral box model, mainly based on two physical phenomena:

The slumping phase. It is assumed that the cylindrically shaped cloud lowers and spreads without mixing with air.

Atmospheric dispersion. Together with slumping it is assumed that, depending on windspeed, due to the shear on the top surface there is a continuous pick-off of gas. The dispersion of the picked-off gas is assumed to be "Gaussian".

The (computer) model consists of routines for the calculation of the Gaussian dispersion from point sources distributed over a continuously growing area. A full description of the model is given in [3]. Although the model is only a rough picture of reality it is quite useful for getting a better insight into cloud behaviour. Until now, there is no evidence that the results are, in general, less reliable than those obtained with more sophisticated models.

5. Comparison of results

For comparison of the results we used the measurements and calculations of concentration curves at the points listed in Table 1. The compared quantity is the maximum concentration at each point. Results are listed in Table 2.

TABLE 2

Measured and calculated maximum concentration (in % v/v) at eight positions in trial No. 008

Trace No.	Full scale measurement	Model measurement	Model calculation field exp.	Model calculation wind tunnel
G04	8.0	2.50	5.02	2.64
G12	4.2	2.11	8.27	3.99
G30	0.7	0.44	1.58	0.95
G02	5.3	3.75	9.39	3.87
G08	2.0	0.44	1.41	1.37
G21	3.1	0.95	3.60	1.81
G13	1.0	0.18	1.52	0.88
G03	0.1	0.45	0.63	0.44

Full-scale values are read from the hard copy data through a "6-s window" to get numbers which are comparable with the model measurements considering frequency response of the measuring system.

Model measurements given in Table 2 are mean values of four measurements. Standard deviation varies from 7—70% of the mean value.

In the model calculations we made two runs. In the first instance we calculated the concentration distribution based on the environmental and source conditions similar to the field conditions for trial No. 008. The results are presented in the fourth column of Table 2. The last column of

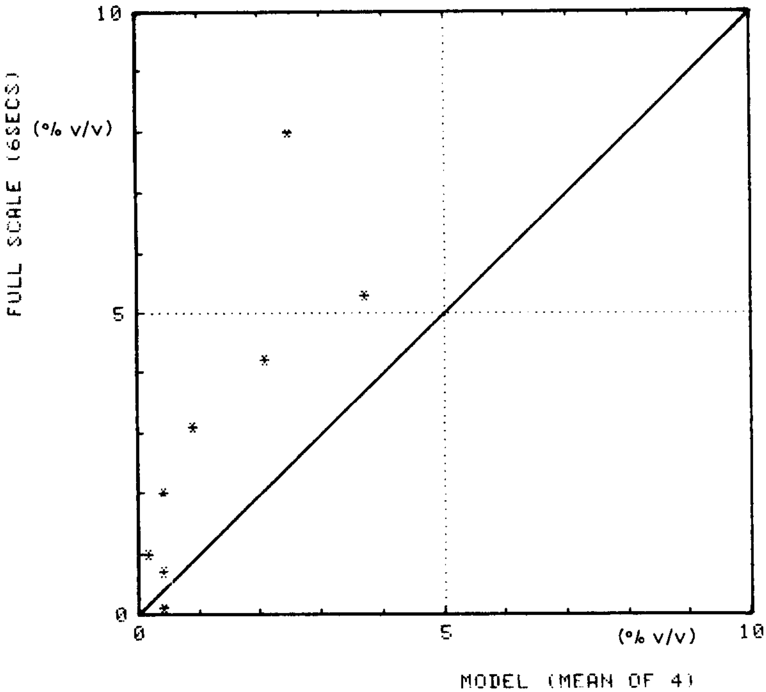
10
FULL SCALE (6SECS)
(% v/v)
5
0
0
5
(% v/v)
10
MODEL (MEAN OF 4)

Fig. 1(a).

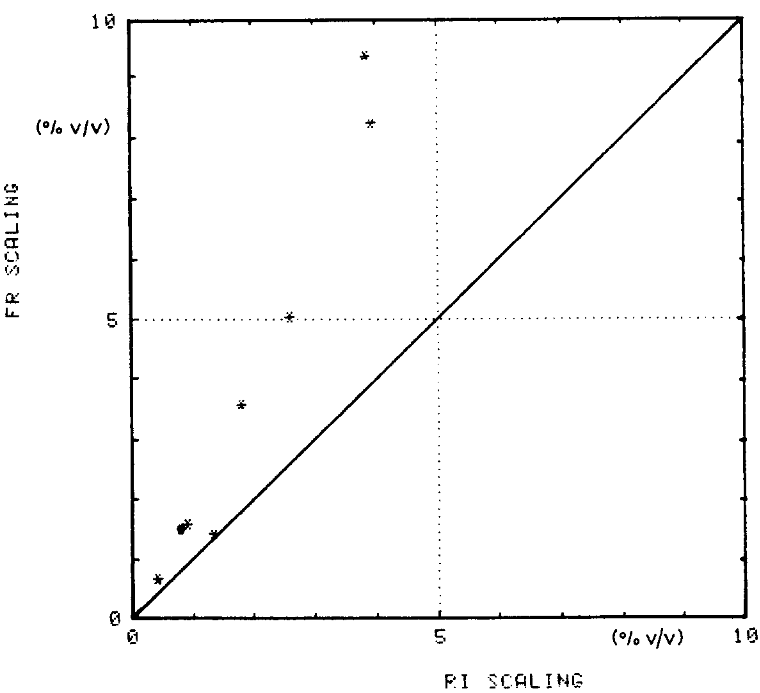
10
(% v/v)
FR SCALING
5
0
0
5
(% v/v)
10
RI SCALING

Fig. 1(b).

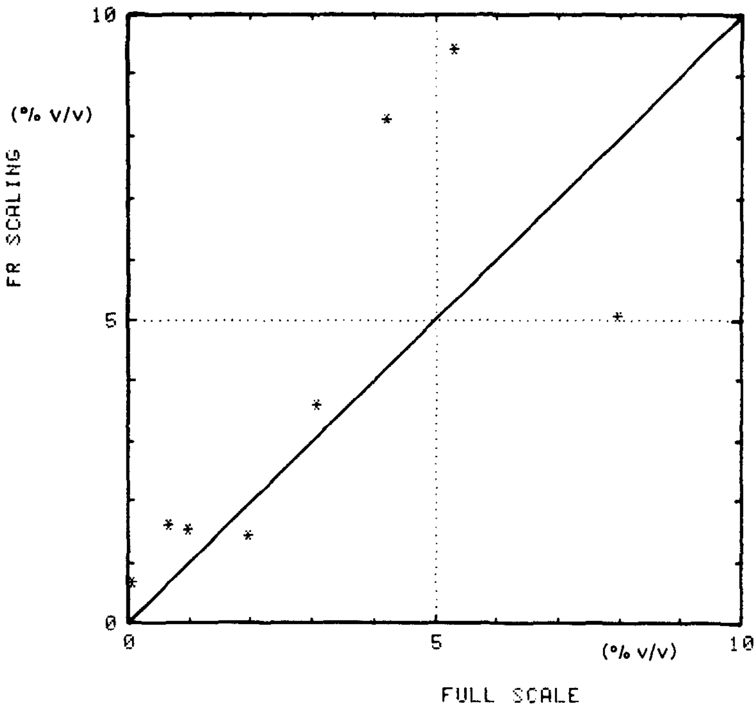
10
(% v/v)
FR SCALING
5
0
0
5
(% v/v)
10
FULL SCALE

Fig. 1(c).

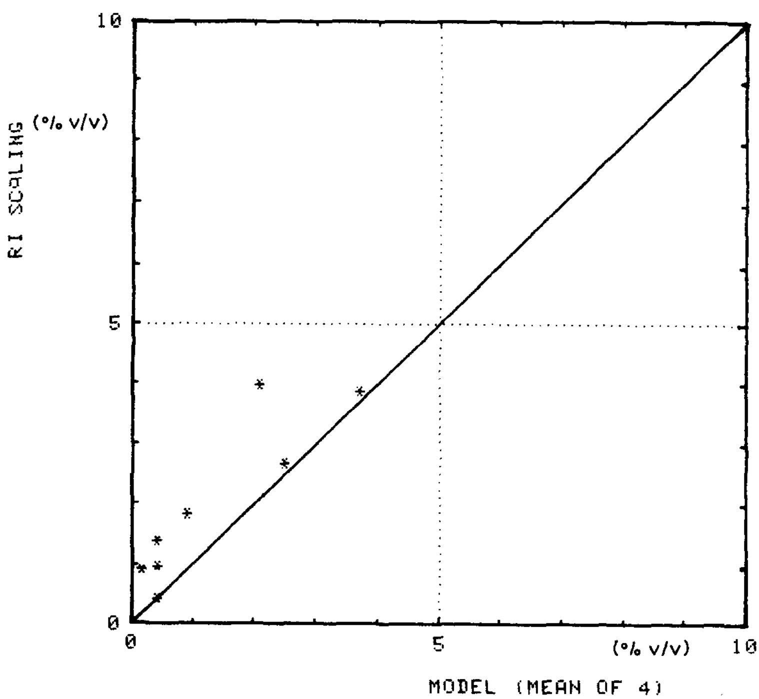
10
(% v/v)
RI SCALING
5
0
0
5
(% v/v)
10
MODEL (MEAN OF 4)

Fig. 1(d).

Table 2 is a repeat set of model calculations with density difference ratio and windspeed adapted to the wind tunnel conditions.

In Figs. 1(a)—1(d) the sets of results are related to each other to show the measure of agreement. The agreement between full-scale measurements and calculated values under the same conditions on one hand and the agreement between model-scale measurements and calculated values both with modified density difference ratio and windspeed (bulk *Ri* scaling) on the other, give rise to the conclusion that the bulk *Ri* scaling may not be allowed in the situation considered, where the ratio of density difference between model scale and full scale is extremely large (> 5).

The measured concentration—time traces are generally lower and have a longer time duration so the integral dose of source gas shows more correspondence in field and laboratory trials than maximum concentration and time duration separately. Future wind tunnel simulations are needed to confirm this statement. The longer time duration of cloud passage in the wind tunnel experiments might be caused by the greater mass contents of the source in these experiments compared to the full-scale trial which results in initial slumping over a larger surface. Because of this larger surface it takes longer for the cloud to pass a downwind sensor position. The same phenomena might cause the lower maximum concentration level. Due to the greater potential energy contents of the source cloud, from which a part is used for turbulence generation during the slumping phase, more air might be mixed in during that phase.

6. Concluding remarks

From the previously depicted wind tunnel simulations and model calculations some interesting conclusions can be drawn. These conclusions must be viewed in the light of the preliminary character of the wind tunnel experiments and the model calculations.

So far, the most important conclusion is that there is some evidence that bulk *Ri*-scaling in a wind tunnel in extreme cases like the one considered here leads to concentration levels which are low compared to the full-scale values. The same conclusion is arrived at in [4]. Future wind tunnel simulations of Phase I HGDT will give more insight in this phenomenon. Visualization of Phase I HGDT in a wind tunnel at a 1 : 100 length ratio gives a similar overall view of cloud behaviour.

Even a simple heavy gas dispersion model, which only makes allowance for the initial slumping due to gravity forces, proves to give reliable results in simplified source and environmental conditions.

Fig. 1. Experimental and calculated maximum concentrations for trial No. 008. (a) Agreement between wind-tunnel model and full-scale results. (b) The calculated effect of bulk Richardson number scaling. (c) Agreement between full-scale results and model calculations. (d) Agreement between wind-tunnel model results and model calculations.

Future wind tunnel simulations to study the bulk Richardson scaling effect can be:
(1) simulation on Froude number basis of trial No. 008
(2) simulation of other trials on Froude number basis
(3) simulation of trial No. 008 with different height over diameter ratio of the source cylinder.

References

1 Heavy Gas Dispersion Trials Thorney Island 1982-3, Data for Trial 008. HSE, RLSD, Broad Lane, Sheffield S3 7HQ, U.K.
2 P.J.H. Builtjes and P.E.J. Vermeulen, Atmospheric boundary layer simulation in the PIA and MIA wind tunnel of TNO-Apeldoorn, MT-TNO Report 80-0290, June 1980.
3 A.C. van den Berg, Berekeningen betreffende de explosieve inhoud van gaswolken met een grotere dichtheid dan lucht (Calculations concerning the explosive contents of gas clouds with a density greater than air), TNO-report PML 1978-10, March 1978 (in Dutch).
4 P.J.H. Builtjes and C.P. Guldemond, Wind tunnel modelling of heavy gas dispersion, Proc. of I. Chem. E. Symp. on Heavy Gas Releases — Dispersion and Control, May 16th, 1984, Utrecht, The Netherlands.