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LARGE SCALE PROPANE RELEASE EXPERIMENTS OVER LAND AT DIFFERENT ATMOSPHERIC STABILITY CLASSES

M. HEINRICH, E. GEROLD and P. WIETFELFT

Technischer Uberwachungs-Verein Norddeutschland e. V.,
GroBe BahnstraBe 31, 2000 Hamburg 54, Germany

ABSTRACT

Large-scale spill tests of liquid propane were performed at a military testsite in northwest Germany. The tests were sponsored by the Bundesministerium fur Forschung und Technologie (Ministry of Science and Technology) of the Federal Republic of Germany.

The primary purpose of the heavy gas dispersion experiments was to determine the lower flammability distance (LFD) of propane for simulated accidental releases under different conditions, according to the requirements of hazard and risk assessment. The tests had the additional aim of providing data sets for testing and/or calibrating numerical dispersion models for heavier-than-air gases. A further objective was to investigate the influence of stable atmospheric stratifications upon the LFD.

The spills were classified in six groups with release rates from 2.5 to 36 kg/s with and without momentum. Additional tests were performed with spill rates up to 61 kg/s. The windspeed varied from 0.1 to 5 m/s with a mean of 2 m/s. The Pasquill stability classes ranged from A to F.

The purpose of this paper is to present preliminary results of 60 spills of large scale liquid propane release experiments over land.

INTRODUCTION

The aim of the described experiments was to determine the Lower Flamability Distance (LFD) for accidental releases of significant amounts of propane (or other heavier-than-air gases) at manufacturing, storage and transportation operations. LFD is the distance between the release point and the location of the 2.1 (vol) % propane concentration in the downwind direction.

The experiments were designed to simulate realistic releases as close as possible. In addition to the evaluation of the data sets for testing and/or calibrating numerical dispersion models, the determination of the LFD itself was a special objective.

The influence of the atmospheric stability has not, in the authors' opinion, been sufficiently considered in previous experiments (refs. 1-5). Special efforts were therefore made to consider a range of atmospheric stability classes. The releases of propane took place over land because extreme stabilities in principle are not found over water.

DESCRIPTIONS OF THE EXPERIMENTS

Test site

The heavy gas was released at the Erprobungsstelle 91 site; a military test field in northwest Germany near the town of Meppen, close to the Dutch border. The test site was about 2.5 km from the nearest village. Only some small streets had to be closed to the public during the test runs. The countryside is used as farmland and is absolutely flat with some ditches and only a few small bushes. About 800 m from the release point a fully equipped automatic meteorological station including a 80-m high steel tower to measure temperature, humidity and wind profiles was provided.

Propane storage and release facilities

In 1985 a propane depot with two tanks of 100-m^3 was erected. A third 100 m^3 tank of nitrogen was used to compensate pressure losses inside the 200 m long pipe (0.2 m diameter) between the tanks and the spill point. Controlled releases of liquid propane could be performed at rates of 2.4 kg/s to more than 36 kg/s by means of a special large flow-controlled motor valve for as long as it was necessary to reach a steady state development of the gas cloud.

The liquid propane was spilled in two ways:

- A nozzle set the propane free in the wind direction so that the momentum of the fluid formed a jet.
- Using a 1-m diameter cyclone to reduce the velocity of the propane, so that the release took place uninfluenced by momentum effects.

In the first case no liquid propane ever reached the ground. In the second case a pool of liquid propane was formed by approximately one-third of the total outflow. The amount of liquid propane was determined after release in a specially-formed ditch.

Meteorologic measurements

Additional to the previously mentioned automatic weather station, four 4-m tall mobile towers were used in the test field. These were equipped with instruments specially designed to measure temperature and wind profiles close to the ground with high resolution.

Occasional turbulence measurements were also made with a Jaijo Denki Super Sonic Anemometer. Only a small part of these measurements have been evaluated up to now.

To evaluate the Richardson number (later used) we used:

$$Ri = \frac{9.81}{273 + t(2)} \quad \frac{(t(16)-t(0.5)) / (16-0.5) - \gamma}{((u(16)-u(0.5)) / (16-0.5))^2} \qquad (1)$$

where t is the air temperature (Celsius) and u, the wind velocity (m/s). The values in brackets indicate the height of the instruments above the ground. γ is the adiabatic lapse rate which had a value of -0.00974 K/m.

Measurements of propane concentration

All concentration measurements took place 0.35 m above the ground which was roughly ploughed soil.

Two types of remote instruments were used. Forty small (volume about 1 litre) catalytic type instruments were regularly distributed over the field. The more important type of instruments consisted of infrared spectrometers which used 3.7 m propane absorption band for detection. With an open pathlength of 0.5 m the interference of water vapour could be eliminated. The calibration of these instruments utilized a built-in spectral filter so that it was extremely stable with a time constant of less than 1 s. In the range from 0 to 3% propane the possible total error was less than ± 0.2% and above 3% it was less than ±5% from the actual value.

Eleven of these instruments were installed shortly before release along the expected centre line of the cloud or in the anticipated region of the 2.1% concentration area of the propane cloud. All voltage outputs were digitalized and transmitted to an IBM PC by a Solarton System which sampled at a rate of 100 points per second.

During all releases the propane clouds were video recorded by a "Umatic" video from a camera on a 10-m mast close to the spill point.

RESULTS

Number of experiments

The results of the 60 spills between November, 1985 and October, 1986 are presented. For 26 of the releases, a cyclone was used; for 34 releases, a nozzle was used. The release rates varied from 2.4 to 61.0 kg/s. The maximum wind speed was 5.1 m/s with the mean being about 2 m/s.

Evaluation of the LFD

The IR instruments were placed corresponding the expected centre line of the propane cloud. From all recorded voltages, the concentrations throughout the release were calculated. In a second step, the maximum (5 s mean) propane concentrations were determined for each instrument. This value and the known distance between the instrument and the spill point were plotted similar to that used by Spicer and Havens (ref. 6). For example, Fig.1, which shows the 5 s averaged maximum concentrations measured by eight instruments during spill 66, illustrates that below 6% propane, the points for the values of concentration as a function of the distance form a straight line on the log-log plot for each spill. It is, therefore, possible to determine the LFD (2.1%) by extrapolation of interpolation. For the two instruments exposed at 300 and 360 m, the centre line of the gas cloud did not match that of the instrument and thus the results are in error.

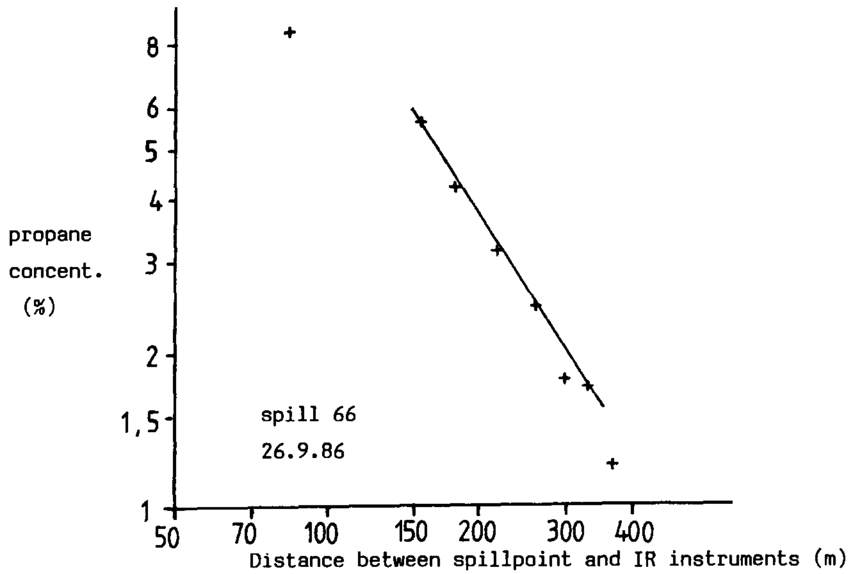

Fig. 1. The 5 s averaged maximum concentrations as a function of distance used to evaluate the LFD.

LFD presentation of 60 spills

Table 1 shows the LFD spills. The following abbreviations are used in the Table.

- n   number of individual spill
- spr   spill rate (propane outflow), kg/s
- spt   spill time (duration of the vent), s
- dia   diameter of nozzle or of the end inside the cyclone in mm
- noz   spill with nozzle
- cyc   spill with cyclone
- wv   wind velocity 2 m about ground, m/s
- st   stability class (Pasquill) by temperature profile
- sr   stability class by net radiation
- Ri   Richardson number by temperature and wind profile between 5 and 16 m

Table 1. LFD of 60 spills

n	date	time	spr	spt	dia	wv	st	sr	Ri	LFD
<u>1985</u>										
11	14/11	14.49	2.8	300	15 noz	0.2	A		-1.75	36
12	12/11	15.28	3.9	300	15 cyc	1.6	A		-2.11	84
14	15/11	15.40	29.5	200	50 noz	2.9	A		+0.016	210
15	15/11	15.55	27.5	270	50 cyc	3.2	C		+0.035	190
16[1]	05/12	16.25	31/43	20/20	80 cyc	3.5	D		+0.204	195
18	12/12	13.00	19.0	200	50 noz	3.7	B		-0.105	205
19	12/12	13.24	21.0	180	50 cyc	3.7	B		-0.083	100
20	12/12	16.39	31.0	185	80 noz	2.2	A		+0.028	270
21	12/12	16.59	29.5	21.0	80 cyc	2.5	B		+0.063	245
<u>1986</u>										
22[2]	09/01	16.32	2.7	240	15 noz	1.6	F		+1.95	58
24	29/01	10.05	3.0	240	15 noz	5.4	D		+0.024	96
26	04/02	08.05	3.0	300	15 noz	4.8	D		0	66
27	05/02	07.46	3.0	300	15 noz	2.0	E		+0.07	76
28	05/02	08.14	3.0	260	15 cyc	1.4	E		+0.152	75
29	06/02	07.34	2.4	240	15 noz	5.1	D		+0.056	76
30	06/02	07.50	30.0	23	80 noz	4.2/ 4.6	D		+0.0585	210
31	06/02	09.00	2.4	170	15 noz	3.8	D		+0.033	58
32	07/02	07.45	2.4	240	15 noz	2.5/ 3.6	D		-0.016	78
33	07/02	08.15	2.4	300	15 cyc	2.9	D		-0.013	64
34	12/02	09.04	2.4	150	15 noz	1.7	E		+0.163	66

35	12/02	15.36	6.0	210	50 cyc	3.7/ 6.0	D		-0.045	115
36	13/02	07.45	6.0	150	50 noz	2.0/ 2.4	E		+0.72	135
37[3]	13/02	08.10	6.0	267	50 cyc	1.6/ 3.0	E		+0.553	90
42	22/05	07.04	6.0	150	50 noz	4.0	D	D	-0.093	155
43	22/05	07.26	6.0	150	50 cyc	4.7	D	D	-0.155	43
44	23/05	07.05	6.0	150	50 noz	2.0	F	D	+0.073	155
45[4]	23/05	08.22	30	120	50 noz	2.1	F	D	-1.22	220
46[5]	23/05	09.02	30	60	50 cyc	1.7	E	C	-0.035	72
51	10/09	07.14	6	200	50 noz	0.2	F	E	+1.104	340
52	10/09	08.08	6	300	50 cyc	1.5	F	D	+0.984	240
53[6]	11/09	06.42	10	300	5o noz	0.6	F		+3.74	260
54	11/09	07.06	10	210	50 cyc	0.7	F		+1.27	238
55[7]	11/08	08.02	4	300	15 noz	0.6	F		+0.822	
56[8]	12/09	08.41	15	510	50 noz	0.4	(F)	(E)		275
57[9]	19/09	06.50	10	300	50 noz	0.4	F		+1.31	370
58	19/05	07.17	10	360	50 cyc	0.5	F		+2.08	240
59	24/09	07.13	6	300	50 noz	0.5	E	D	+1.096	212
60[10]	24/09	07.42	6	300	80 cyc	0.2	E	D	+0.744	115
61[11]	25/09	06.44	2.5	600	15 noz	0.1	F	F	+43.9	198
62[12]	25/09	07.17	61	60	80 cyc	0.2	F	F	+46.0	180
63[13]	25/09	07.39	2.5	520	80 cyc	0.4	F	F	+48.3	154
64[14]	25/09	08/29	6	120	80 cyc	0.1	F	D	+3.78	162
65	26/09	06.50	2.4	600	15 noz	0.3	F	E	+0.33	120
66	26/09	07.17	6	300	50 noz	0.2	F	E	+1.26	288
67[15]	26/09	07.59	2.9	420	15 cyc	0.5	F	D	+4.77	30

68	26/09	08.18	6.2	500	50	cyc	0.7	F	D	+0.137	120
69	01/10	06.03	2.4	600	15	noz	0.4	F	F	+0.403	200
70	01/10	06.31	6	600	50	noz	1.6	F	E	+0.168	280
71	01/10	07.08	6	600	50	cyc	0.8	F	E	+0.207	180
72	01/10	07.39	6	600	50	cyc	0.9	F	D	+0.018	185
73	10/10	13.56	6	300	50	noz	2.7	B	C	-2.66	47
74	01/10	14.18	6	300	50	cyc	3.0	B	C	-0.833	56
75[16]	03/10	05.50	36	30	80	noz	0.6	F	E	+0.206	265
76[17]	03/10	06.06	36	60	80	noz	0.3	F	E	+1.504	275
78	03/10	06.58	36	240	80	cyc	0.8	F	E	+3.28	
79	09/10	11.02	36	80	80	noz	4.0	B	C	-0.243	240
80	09/10	11.25	7.5	120	50	noz	3.2	B	C	-0.754	110
81	09/10	11.46	53	80	80	cyc	4.0	B	C	-1.019	90
82	10/10	09.44	36	120	80	noz	3.4	C	D	-0.043	215
83	10/10	10.03	36	120	80	cyc	3.4	B	C	-0.153	135

1 Two nearly instantaneous releases with only a short interval between them. The LFD relates to the second release.

2 The direction of the nozzle and the wind direction were at right angles.

3 Sunrise was at 7.33. Probably the lowest layer already was unstable.

4 The lowest layer probably was unstable due to solar radiation.

5 No steady state was reached.

6 LFD probably is much larger. The instrument exposed at the greatest distance showed a maximum of 8% propane.

7 Nozzle upwards.

8 Stability class estimated.

9 Very flat cloud, about 5 m.

10 Circular cloud.

11 Height of the visible cloud about 1 m.

12 The height of the circular cloud was only 0.4 m. No steady state reached.

13 Circular cloud.

14 Circular cloud.

15 The lowest layer became unstable during the spill from solar radiation.

16 No steady state reached.

17 No steady state reached.

Preliminary interpretation

A preliminary interpretation of the spills classified the results into six groups relative to the spill rates of 2.5, 6 and 30 kg/s for both cyclone and nozzle releases. Only for the cyclone releases was about two-thirds of the outflowing propane formed into a gas cloud while one-third was retained in a liquid pool; the evaporation time of the pool varied from 1 to 3 hours.

Only three tests were run at a spill rate of 2.5 kg/s using the cyclone. The only spill at a very stable atmospheric stratification shows a LFD about twice as large as the LFD for the other two at nearly neutral situations.

The nozzle releases also show a doubling of the LFD for very stable situations compared to the neutral cases.

For each test class the LFD are presented as a function of the Richardson number. To prevent a cluster of dots for values of Ri around zero the scale was made proportional to the third root of the Richardson number.

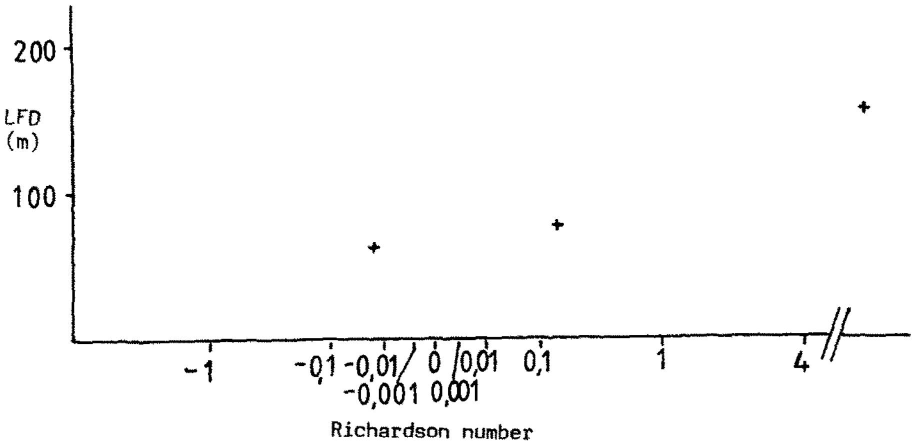

Fig. 2. Relationship between LFD and Ri. Spill rate 2.5 kg/s, cyclone.

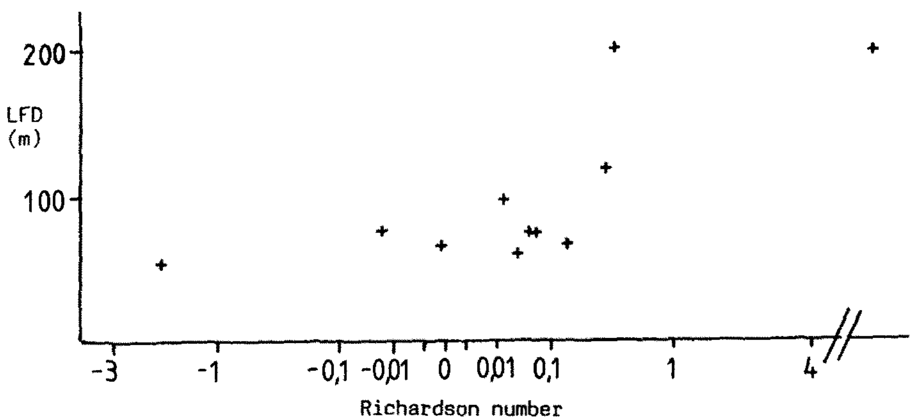

Fig. 3. Relationship between LFD and Ri. Spill rate 2.5. kg/s, nozzle.

In Fig. 4, a large variation in LFD can be seen. The Richardson number is not the only parameter that influences the LFD; in this situation, for example, the lowest LFD of 43 m for spill 43 rather clearly depends on the comparatively high wind velocity of 4.7 m/s also. On the other hand, the wind velocity was 1.5 m/s for spill 52 and a LFD of 240 m was obtained. The relationship between LFD and wind velocity shows a maximum of LFD at 1.5 m/s but only a weak dependency of the wind velocity itself.

The largest span of the LFD has been found by using a nozzle to release liquid propane in the wind direction. For spill 73, the LFD was 47 m compared to 340 m for spill 51 under stable conditions. In the first case the windspeed was 2.7 m/s and the visible cloud was short. In the second case at the low wind velocity of 0.2 m/s the cloud was seen to accumulate propane for a long period of time before a steady state was established.

There was not enough values of this spill class at the higher Richardson numbers to make a decision whether the LFD increases with Ri or not, because of the lack of further experiments.

Although the LFD for this spill class seems to form a horizontal line in the graph, it is probable that at very stable conditions the LFD increases strongly. At both spills 75 and 76, no steady state was reached because the tests were terminated due to the fact that the spill cloud had become much larger than the test field layout.

Fig. 2-7 shows the strong dependence of LFD on the Richardson number; the dependence decreases with spill rate. This relationship is important in the determination of safety

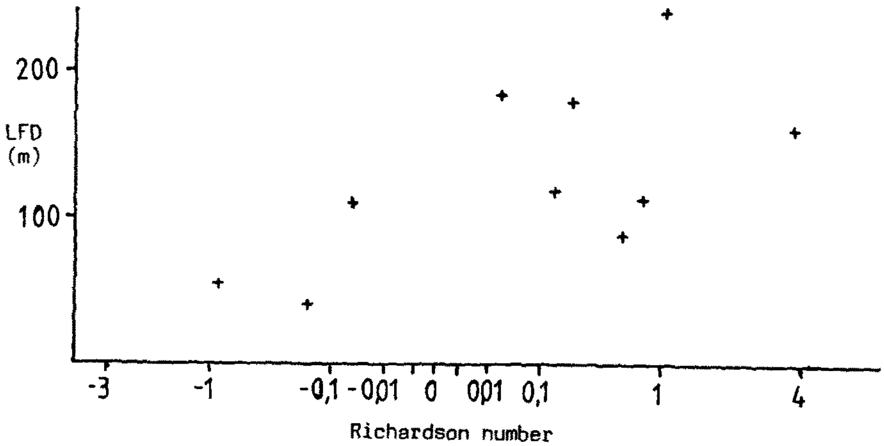

Fig. 4. Relationship between LFD and Ri. Spill rate 6 kg/s, cyclone.

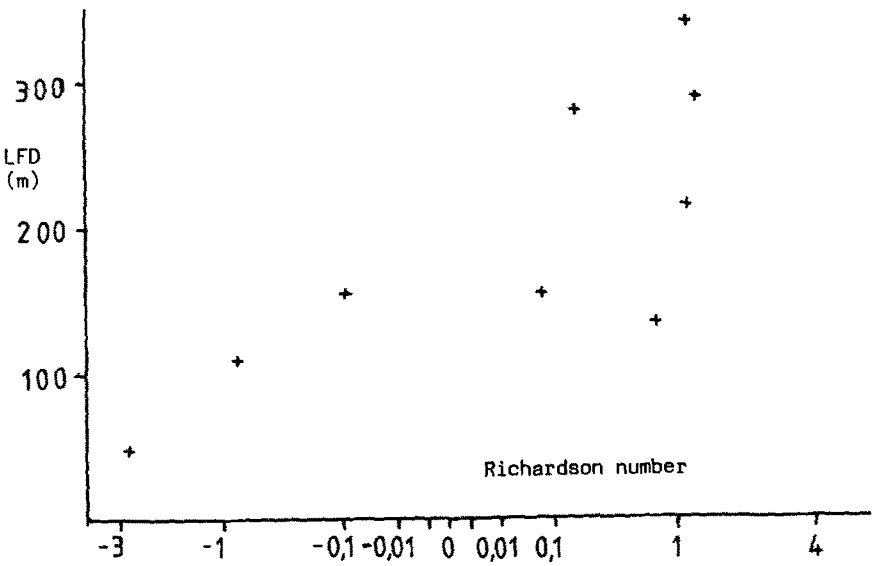

Fig. 5. Relationship between LFD and Ri. Spill rate 6 kg/s, nozzle.

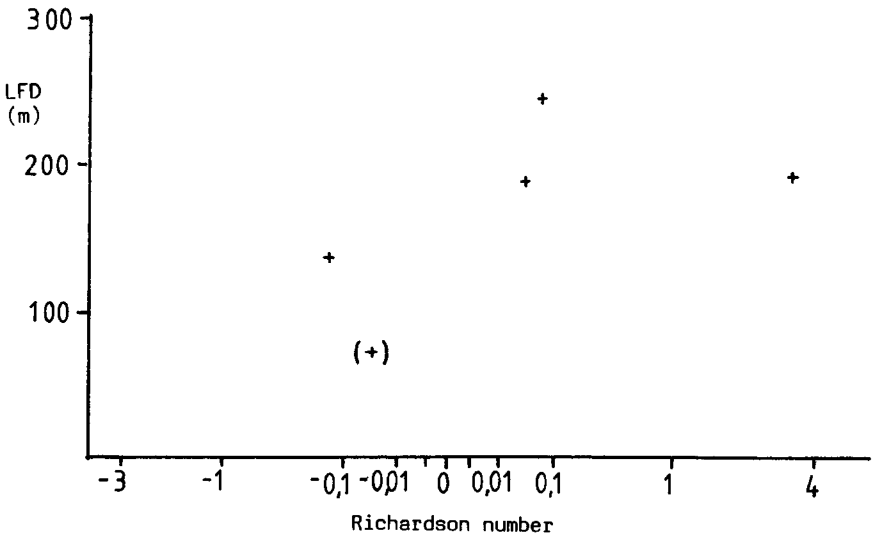

Fig. 6. Relationship between LFD and Ri. Spill rate 30 kg/ s, cyclone.

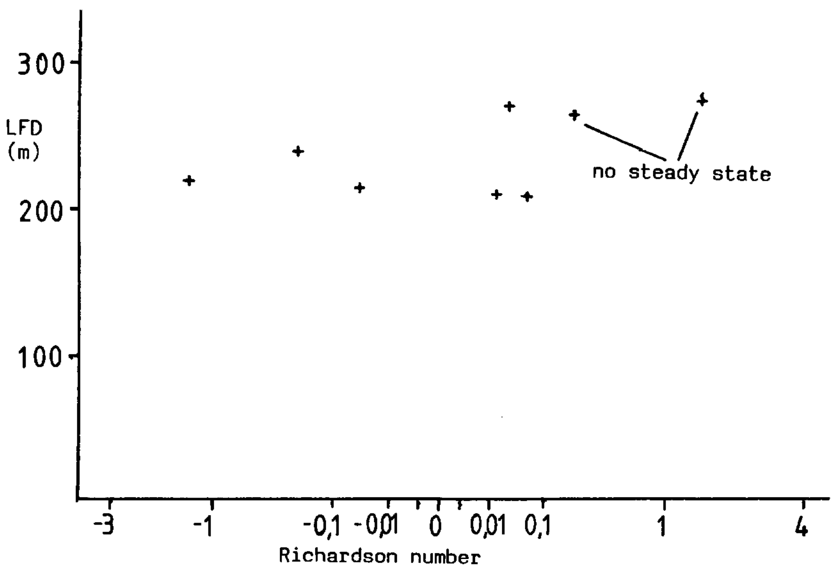

Fig. 7. Relationship between LFD and Ri. Spill rate 30 kg/s, nozzle.

distances because the largest LFD occur just with atmospheric conditions having a strong temperature gradient at the surface, such as with inversions at night. Thermal stratification thus influences the results significantly. It is questionable whether wind tunnel experiments can reproduce all such field experiments.

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