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Explosion venting of bucket elevators

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Abstract

This paper is a report of an experimental programme on the explosion protection of bucket elevators by venting. The project was a collaborative effort with funding by the Health and Safety Executive and manufacturers and users of bucket elevators through the British Materials Handling Board. Two bucket elevators were used in the project—a single leg elevator and a twin-leg elevator. Four dusts were used with K_{St} values up to 211 bar m s^{-1} and dust clouds were produced by dust injection and by normal operation. Reduced explosion pressures were measured and guidance has been derived from the results. This guidance is in terms of vent spacing as a function of the K_{St} value of the dust. Crown Copyright © 2002 Published by Elsevier Science Ltd. All rights reserved.

Keywords: Dust explosion; Venting; Bucket elevators

Bucket elevators are widely used in the handling of large quantities of bulk powders and are normally the preferred means of conveying where long vertical lifts are required for free flowing powders/granular products. As such they are to be found in nearly all animal feed mills, bulk grain stores and many of the larger installations handling powders in the food industry. Powder or granular products inevitably spill from the buckets during operation and fall down the upleg of the elevator. The finer material is likely to remain in suspension while the coarser material falls back to the boot. At the top of the elevator most of the powder will discharge down the off-take chute, but some will normally be carried over into the downleg of the elevator. Thus both legs are likely to contain a dust cloud of unknown concentration, constantly agitated by the moving buckets, all the time the elevator is in operation. Various sources of ignition are foreseeable in such units and explosion incidents have been reported.

Explosion venting is one method for explosion protection of bucket elevators. The current Institution of Chemical Engineers guidance requires that the vents—equal in cross sectional area to the limb—are positioned according to the guidance for ducting. Alternatively, a spacing of 6 m between vents is used. The guidance also requires that the top casing and the boot must be explosion relieved (Lunn, 1992).

There appears to be no guidance from other European organisations such as the German VDI, but the USA National Fire Protection Association document NFPA-91: Fires and dust explosions in agricultural and food products facilities gives guidance in somewhat more detail than Lunn (1992) but still recommends a vent spacing of approximately 6 m.

There is, however, no evidence that any current guidance spells out the optimum venting requirements of elevators, and there is little published work on elevator explosion tests. Gillis and Fishlock (1982) carried out venting and suppression experiments on a twin leg elevator and some guidance was given.

This paper describes an experimental programme, a collaborative effort by the Health and Safety Executive and manufacturers and users of bucket elevators under the British Materials Handling Board, in which explosion venting of bucket elevators was studied using a single leg elevator and a twin leg elevator with a number of flammable dusts. Reduced explosion pressures have been measured and the results used by the Health and Safety Executive to develop guidance for practical use.

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1. Experimental

Two bucket elevators have been used in this programme: a single leg elevator and a double leg elevator. Both elevators were mounted in a tower with access levels at 2.7 m intervals.

1.1. Single leg elevator

A schematic diagram of the elevator is shown in Fig. 1. The single leg steel casing is rectangular in shape, with a cross section of 1.22 m×0.945 m, in which the chain linked buckets of nominal dimensions 540 mm wide×280 mm×390 mm, with a spacing of approximately 450 mm, run up and down. It has a fixed speed drive mounted at the head of the elevator powered by an 11 kW motor and gearbox that drives the buckets at a speed of approximately 35 m/min. The drive pulley and a deflector pulley are mounted within the head of the elevator and a return pulley is mounted at the boot of the elevator.

Explosion relief vents were installed at each level, including the top face of the elevator, with dimensions equal to the nominal cross section of the elevator casing (1.22 mm×0.945 m), apart from level 8 where, because of the restriction of supporting steel members, a slightly smaller vent was installed—0.945 m×0.7 m. Plastic vent panel closures were used for the majority of the tests. Stainless steel vent panels were also used in some of the tests.

Dust injection cylinders were located at each of the nine levels at intervals of 2.7 m. Their position at each level alternated from side to side. Distribution of the dust injection points along the elevator enabled a well-dispersed dust cloud to be produced throughout the elevator casing. An ignition source could be fitted at level 1, level 5 or level 9 (see Fig. 1). Pressures were measured at up to nine positions along the full height of the elevator.

1.2. Twin leg elevator

The twin leg elevator (Fig. 2) was supplied by Carier Bulk Materials Handling Ltd and represents a typical elevator used in the bulk handling industry. The casing was designed to a stronger specification than normal to

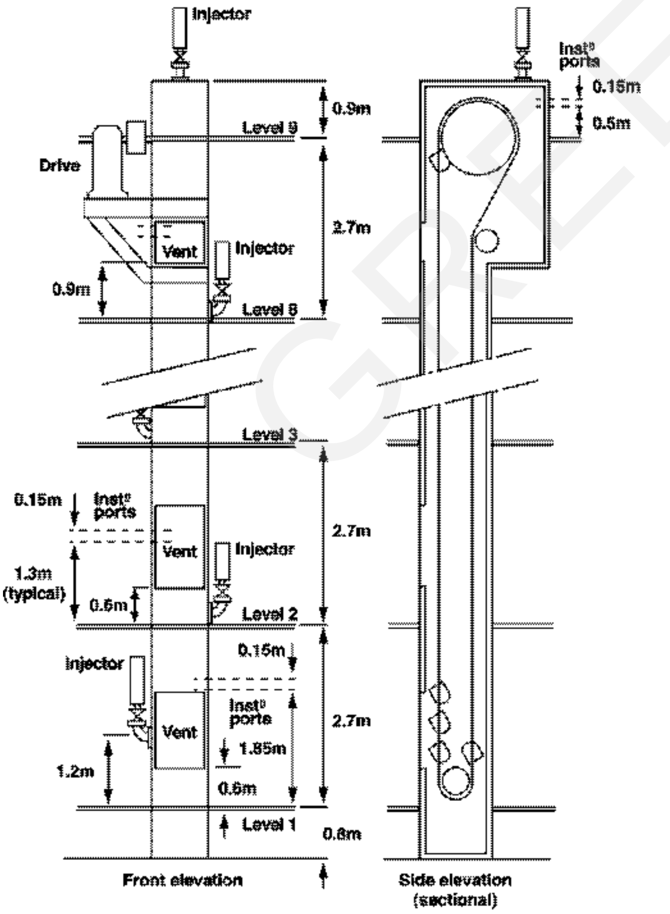

Fig. 1. Single leg bucket elevator.

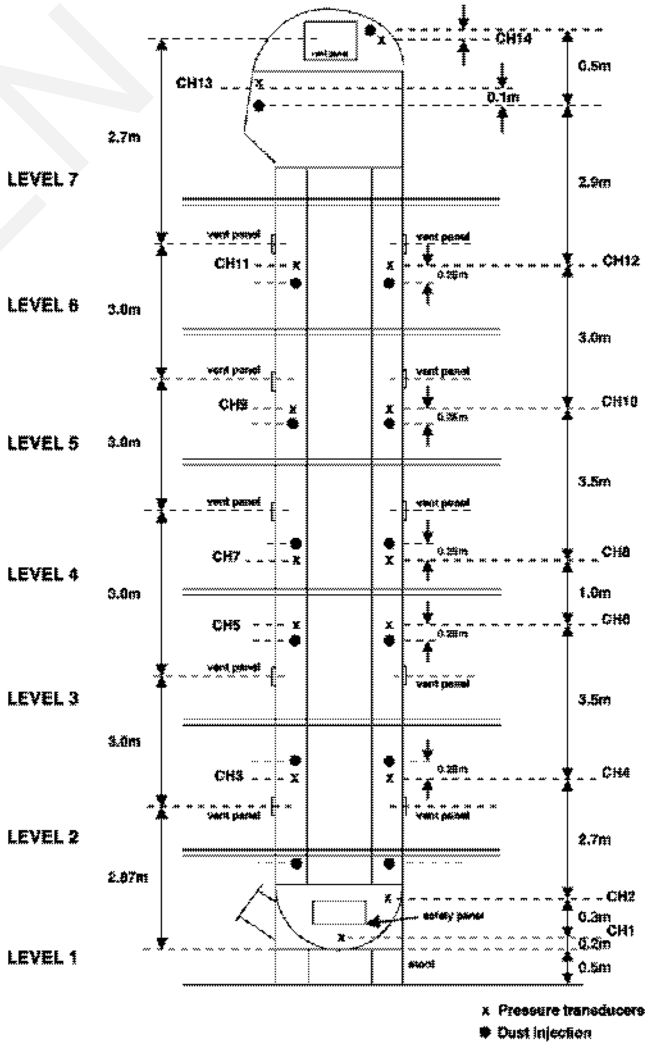

Fig. 2. Twin leg bucket elevator.

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enable it to withstand the explosion pressures developed in the tests. The elevator head, boot and a 1.5 m long leg section were each hydrostatically tested to 1.5 bar g. The overall height from the base of the boot to the top of the head section was 17.75 m.

The maximum dimensions of the steel buckets were 308 mm wide×175 mm deep×130 mm high and were bolted to the 320 mm wide rubber belt. The belt was driven by the 0.6 m diameter crowned head pulley at a speed of 3 m/s. Typically, when full to capacity, each bucket would carry approximately 1.7 kg of cornflour or 1.3 kg of milk powder. Discharge takes place by centrifugal action as the buckets pass around the head pulley.

The design clearances are, approximately: between the tip of the buckets and the front of the casing: 70 mm, between the sides of the buckets and casing: 41 mm, and between the rear of the belt and the casing: 55 mm.

Explosion relief vent openings were installed at approximately 3 m intervals on both legs and measured 305 mm wide×457 mm high (0.139 m^2). The bottom edge of the first relief panel was 2.875 m from the base. A single explosion vent was located at the side of the head. Either aluminium foil or proprietary stainless steel panels with a nominal burst pressure of 100 mbar were used as the vent closures. The cleaning door at the boot was modified to incorporate a safety panel designed to protect the boot in the event of excessive pressure. This was covered with a strong burst panel with a bursting pressure in excess of 400 mbar.

Dust could be dispersed into the elevator using a pressure injection system or by a recirculation system. Dust was injected into each leg at each level simultaneously via nozzles located flush with the inside of the casing. Pairs of nozzles were positioned at each level. Seven injector assemblies were fitted to the elevator, one at each floor level.

In the recirculation system, dust is initially loaded into the elevator via a chute at the bottom of the up-leg and conveyed to the head where it is discharged into a recycle leg. The discharged dust falls under gravity through the leg to the elevator inlet and is reconveyed back up the elevator. The recycle leg has a square cross section measuring 250 mm×250 mm and incorporates an intermediate 2 m^3 capacity holding bin. The bin and the leg are protected by explosion relief panels. The bin is fitted with two explosion relief panels on the top face and the recycle leg has four explosion panels. Removal of dust from the elevator is achieved by directing the dust, as it flows from the bin, to a discharge duct by the operation of a diverter valve. The diverter valve is located 3 m below the bin.

The ignition source was installed in the elevator casing at either level 1 upleg (close to the boot), level 7 (close to the head of the elevator) or at an intermediate point in the leg (see Fig. 2). Explosion pressures were measured at 14 points, located in both legs at 3 m intervals.

1.3. The dusts

Four dusts were used in the tests:

milk powder: K_{St}=86 bar m s^{-1}, P_{max}=7.4 bar g;
cornflour A: K_{St}=147 bar m s^{-1}, P_{max}=7.9 bar g;
cornflour B: K_{St}=211 bar m s^{-1}, P_{max}=8.0 bar g;
cornflour C: K_{St}=180 bar m s^{-1}, P_{max}=8.7 bar g.

2. Experimental results

2.1. Single leg elevator

A series of tests was performed to determine the optimum conditions of injection pressure, dust concentration and ignition delay that produced the highest explosion pressures. The optimum conditions were used throughout the main test programme.

2.2. Effect of ignition position

Three ignition positions have been used in the complete series of explosion tests—top (level 9), middle (level 5) and bottom (level 1) of the elevator. The results show that any one position is not significantly more hazardous than the others. There was a tendency, where the ignition source was located at level 1 or level 9, for the peak pressure to be measured at level 9. The likely cause of this is the congestion in the elevator head, with buckets, drive and deflection pulley wheels all mounted in close proximity—these obstacles would tend to produce enhanced turbulence and act to restrict the venting of the explosion.

When the igniter was located at level 5 the explosion propagated towards the head and the boot and resulted in peak pressures at a range of locations. Although there was no definite pattern to the location of the peak pressure, its most frequent location was at level 9.

2.3. Effect of moving buckets

The results showed that operation of the buckets had no significant effect on the reduced explosion pressure compared to when the buckets were stationary.

2.4. Measurements of reduced explosion pressure

A series of experiments was performed with milk powder, cornflour ‘A’ and cornflour ‘B’, using vent closures with various opening pressures. The opening pressure of a vent closure was measured during each test so that an indication could be obtained of the overpressure

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at which the venting process began. Initially, tests were done with all vents acting as explosion relief; as the programme proceeded vents were progressively blanked off to decrease the available venting area.

The overpressure that develops at different points in the bucket elevator depends on the ignition position and the number of vent openings. Some examples of the pressure variation along the elevator during an explosion are given in Table 1. Numbers 1–9 in Table 1 are cornflour ‘A’ tests; 10–13 are cornflour ‘B’ tests. Variations in the dust dispersion, explosion propagation and pressures at which vents open lead to a spread of maximum reduced explosion pressures for nominally identical experiments.

The results have been analysed by plotting the maximum value of reduced explosion pressure measured in a particular test, P_{red}, against the vent opening pressure measured during the test, P_{stat}.

2.4.1. Cornflour ‘B’

Fig. 3 shows all relevant test results using Cornflour ‘B’, for various explosion-venting arrangements.

2.4.2. Cornflour A

Fig. 4 shows all the relevant test results using cornflour ‘A’.

2.4.3. Milk powder

Explosions of milk powder generated very low pressures, and, often, pressures were not sufficient to burst any of the vent covers. In the explosion tests that did burst the vent covers, pressures did not rise beyond the bursting pressure of the cover.

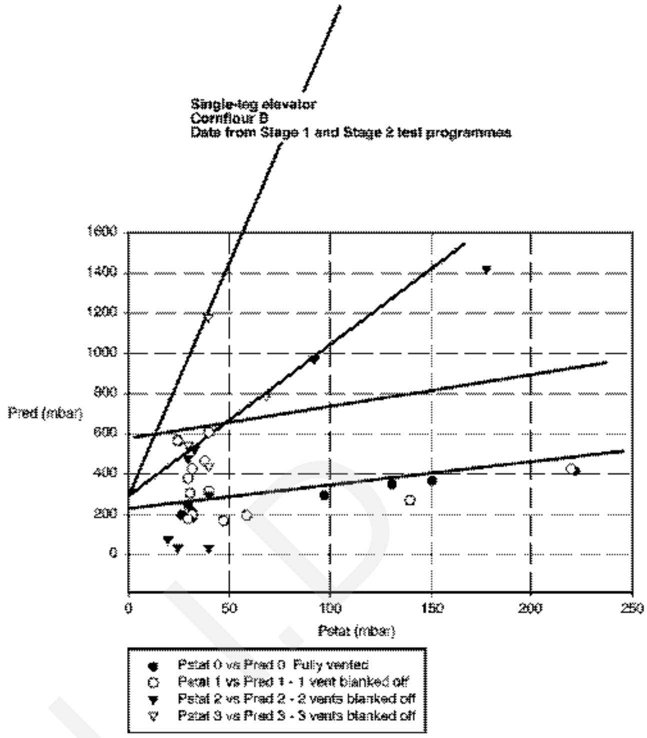

Fig. 3. Reduced explosion pressure vs vent bursting pressure.

2.5. Analysis of the results

In order to produce a worst-case analysis of the results, the points for different total vent areas have been enveloped by straight lines. From each of these lines, an upper value of the reduced explosion pressure at P_{stat} values of 0.1 bar and 0.05 bar has been estimated. These pressures are plotted against the total vent area in Figs. 5 and 6, respectively. The total vent areas necessary to

Table 1
Explosion pressures in single-leg elevator tests

	Vent covers blanked off	Ignition location	Pressures				
			Level 1 (mbar)	Level 3 (mbar)	Level 5 (mbar)	Level 7 (mbar)	Level 9 (mbar)
1	levels 1, 9	level 1	150	220	100	120	130
2	levels 1, 4, 7	level 5	220	180	200	60	230
3	levels 1, 4, 7	level 1	80	100	300	260	270
4	levels 2, 4, 6, 8	level 5	240	300	180	170	280
5	levels 4, 8	level 1	60	50	180	120	140
6	levels 4, 8	level 5	150	240	90	110	110
7	level 9	level 9	60	90	130	120	170
8	levels 2, 3, 4, 5, 6, 7, 8	level 5	440	690	680	840	350
9	levels 2, 3, 4, 5, 6, 7, 8	level 5	609	1410	1360	1370	770
10	levels 1, 9	level 9	230	100	280	140	530
11	levels 1, 4, 7	level 5	350	300	550	160	530
12	levels 1, 4, 7	level 9	450	250	440	310	160
13	level 9	level 9	140	160	160	550	610

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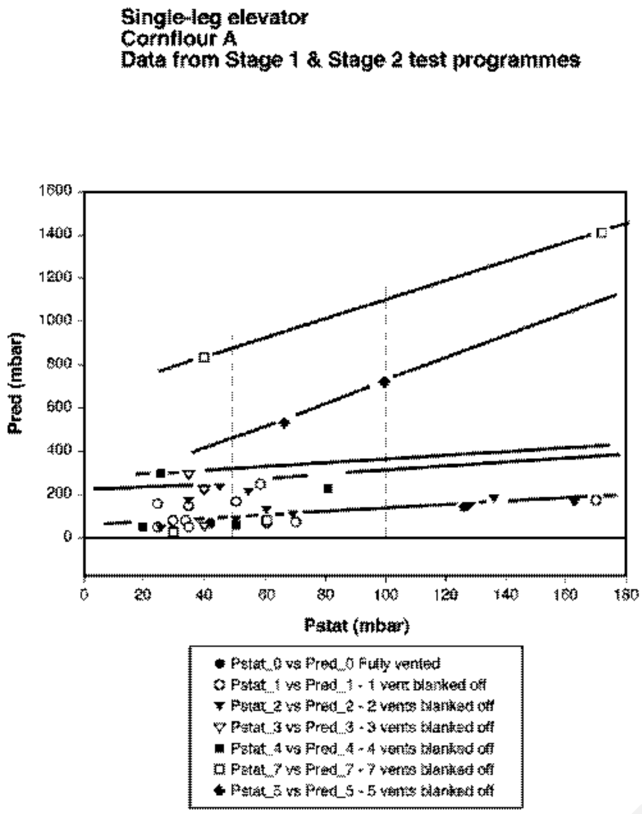

Fig. 4. Reduced explosion pressures vs vent bursting pressure.

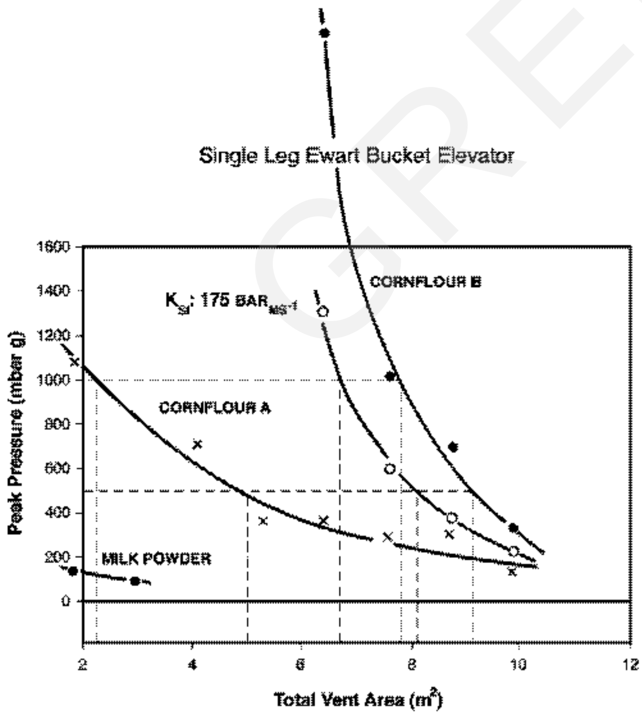

Fig. 5. Explosion pressure vs total vent area at a vent opening pressure of 0.1 bar.

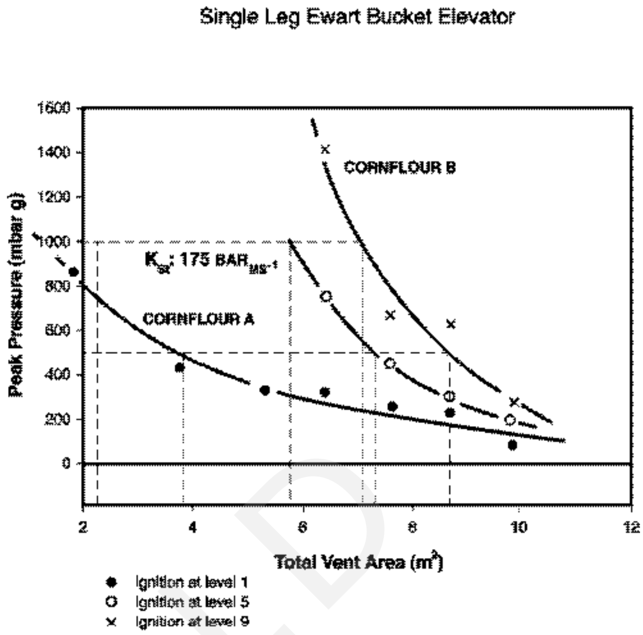

Fig. 6. Explosion pressure vs total vent area at a vent opening pressure of 0.05 bar.

limit the reduced explosion pressure to either 0.5 bar g or 1 bar g have been marked on Figs. 5 and 6. The results for milk powder have been included on Fig. 5. The lines for K_{St}=175 bar m s^{-1} have been obtained by linear interpolation.

2.6. Twin leg elevator

Because there is a relatively large space around the buckets in a single leg elevator, it is generally easy to propagate a flame through the entire casing. In a twin leg elevator, however, the space around and between the buckets is limited and it is unclear, at first sight, whether the buckets either act as turbulence inducers in the flow ahead of the flame and thus cause the explosion to accelerate, or act as obstacles to flame propagation and so decrease the explosion velocity or prevent its propagation altogether.

In order to answer this question, explosion tests were done in which all buckets were removed from the elevator and then replaced in stages until a full complement was re-fitted. The guidance derived from these results is based only on the tests with a full complement of buckets.

2.7. Effect of ignition location

With vents at 3 m intervals (fully vented) and no buckets installed, the most effective location of the ignition source for explosions of cornflour ‘A’ was at the head; with cornflour ‘B’ explosions the most effective location was at the boot. However, when buckets were

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installed, the explosion pressure tended to increase when the igniter was located at level 7. Therefore, in the majority of tests the ignition source was located in the elevator head at level 7. This was at a point in the head where the free volume was greater than elsewhere in the elevator and so maximum development of the primary explosion would occur prior to the expanding flames making contact with the elevator walls and buckets.

2.8. Effect of bucket spacing—fully vented elevator

Tests were carried out, initially, without buckets installed, followed by tests with a range of bucket spacings with the buckets running. In principle, the presence of the buckets could produce two effects: (a) inhibit flame propagation, (b) increase turbulence of the flame. The elevator was fully vented, with vents at 3 m intervals and with a vent at the head. A range of ignition locations was used.

Without the buckets installed, flames of both cornflour ‘A’ and cornflour ‘B’ propagated through the elevator. The more reactive dust, cornflour ‘B’, produced a slightly higher peak pressure (211 mbar) compared to cornflour ‘A’ (191 mbar).

To test the flame blocking ability of the buckets, they were installed at 3 m spacing and were positioned between the vents in a stationary position. In the stationary mode the buckets prevented propagation of the cornflour ‘A’ flame and the pressure did not exceed the burst pressure of the explosion panels; cornflour ‘B’ flames propagated through the elevator and the explosion pressure increased to 275 mbar. In the running mode, the buckets still inhibited flame propagation with cornflour ‘A’. However, cornflour ‘B’ flames still propagated through the elevator, with the explosion pressure further increased, to 314 mbar. This provides evidence that the presence of the buckets increased the turbulence in the case of cornflour ‘B’ explosions but the buckets inhibited flame propagation with cornflour ‘A’, although this was not always the case. In one test with 1 m spacing of the buckets, the elevator running and ignition at the head, a cornflour ‘A’ flame propagated past the buckets from the head to the boot after which it propagated up the downleg, producing 273 mbar at the boot—a pressure comparable with a cornflour ‘B’ explosion that produced 265 mbar, in a nominally identical test.

The results in Table 2 demonstrate the progressive increase in explosion pressure with cornflour ‘B’ as the number of buckets in the elevator increases. With cornflour ‘A’, however, the buckets tended to inhibit flame propagation, producing accompanying low pressures.

Table 2
Peak explosion pressures—fully vented twin leg elevator

	Peak explosion pressure—cornflour ‘A’	Peak explosion pressure—cornflour ‘B’
No buckets	191	211
Buckets at 3 m spacing	110	314
Buckets at 1 m spacing	273	265
Buckets at 0.28 m spacing	117	519
Buckets at 0.14 m spacing	110	659

2.9. Explosion tests with varied vent configurations

The peak explosion pressures were measured for a range of vent configurations using the four dusts. The buckets were running in all the tests. Some typical results are given in Table 3, demonstrating the variation of pressure along the elevator and the behaviour of the flame.

Pressure data from the tests with the buckets spaced at 280 and 140 mm have been plotted and are presented in Figs. 7 and 8, respectively.

Vent spacing was set at 3, 6 and 12 m. Generally, flame propagation was rare with cornflour ‘A’ and peak pressures were measured usually close to the ignition—in the head. Cornflour ‘B’ explosions propagated into the elevator legs and to the boot, with peak pressures measured either in the boot or the upleg. Explosions of cornflour ‘C’ also propagated into the upleg to the boot and into the downleg. In one test, with a vent spacing of 6 m, the primary explosion in the head propagated to the boot via the downleg in the direction of the bucket travel and propagated to level 3 in the upleg. A secondary flame then re-emerged at level 5 in the downleg and persisted for approximately 4 s at the vent after which the flame re-emerged at level 5 in the upleg and at the head, thus demonstrating how unpredictable flame propagation can sometimes be. No flame propagation took place in any of the milk powder tests.

2.10. Tests with the recirculation system

These tests were performed to check that worst case conditions were being tested by dust injection tests and that the test programme adequately covered explosions experienced during actual running.

The elevator was cleaned out and the appropriate vent configuration was installed. Cornflour was manually loaded into the elevator boot and the elevator was run for approximately 3–4 min to recycle the dust before the igniter was fired. The test conditions were:

Cornflour ‘A’ recycle tests
Dust: cornflour ‘A’
Bucket spacing: 280 mm
Igniter positions: level 7 (hood)
Vent configurations: vent spacings 12 m
Dust loading: 175–200 kg
Cornflour ‘B’ recycle tests

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Table 3
Pressures in some twin-leg elevator tests

Dust	Pitch of the buckets (m)	Vent covers Blanked off	Peak pressures (mbar)				Comments
			Boot	Upleg	Downleg	Head	
Cornflour ‘B’	0.28	none	519	190	306	176	Flame propagated down both legs to the boot.
Cornflour ‘B’	0.28	levels 2, 4, 6	563	484	224	215	Flame propagated down the upleg to the boot and up the downleg.
Cornflour ‘B’	0.28	levels 2, 4, 6	610	650	350	280	Flame propagated down the downleg to the boot and up the upleg.
Cornflour ‘B’	0.28	levels 2, 4, 6	847	402	157	123	Flame propagated from the head down the upleg and up the downleg
Cornflour ‘B’	0.28	levels 2, 4, 5, 6	640	332	293	260	Flame propagated from the head to the vents at level 3
Cornflour ‘B’	0.28	levels 2, 4, 5, 6	300	3031	921	194	Flame propagated from the head to the vents at level 3
Cornflour ‘B’	0.14	none	659	300	402	117	Flame propagated down both legs
Cornflour ‘B’	0.14	levels 2, 4, 6	1320	1303	420	875	Flame propagated down the downleg and then into the upleg with flame from level 5
Cornflour ‘C’	0.14	none	221	143	169	118	Flame propagated from the head down the downleg and up the upleg to the head
Cornflour ‘C’	0.14	levels 2, 4, 6	356	319	233	129	Flame propagated from the head down the downleg and up the upleg to the head
Cornflour ‘C’	0.14	levels 2, 4, 5, 6	570	517	330	329	Flame propagated from the head down the downleg and up the upleg to the head
Cornflour ‘C’	0.28	levels 2, 4, 6	780	777	418	175	Repeat of test 95, flame propagated down the downleg and up the upleg with further secondary flame
Cornflour ‘C’	0.28	levels 2, 4, 5, 6	108	135	140	155	No flame propagation
Cornflour ‘C’	0.28	levels 2, 4, 5, 6	306	200	951	138	Flame propagated in the downleg to level 3

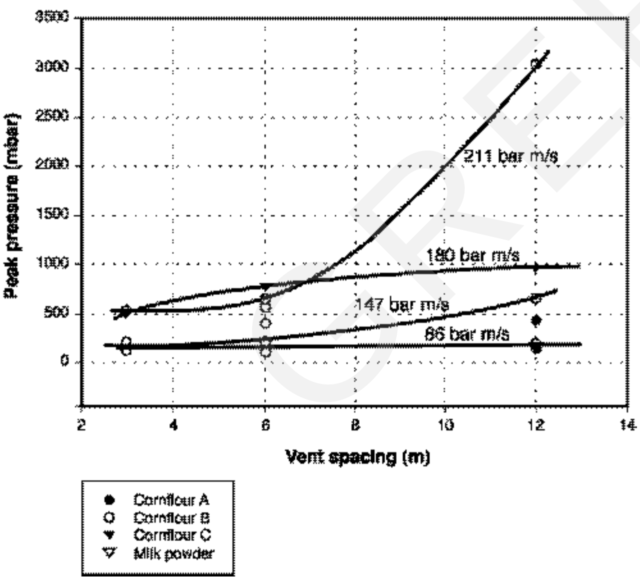

Fig. 7. Explosion pressure vs vent spacing. Buckets at 280 mm spacing; vent opening pressure=0.1 bar. Twin leg elevator.

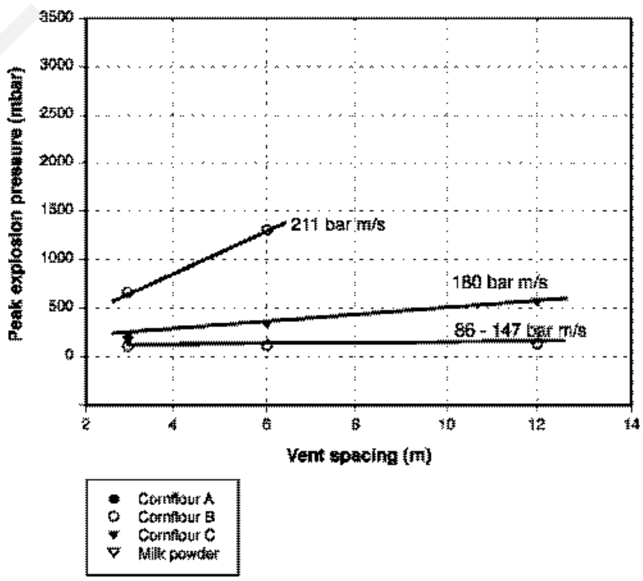

Fig. 8. Explosion pressure vs vent spacing. Buckets at 140 mm spacing; vent opening pressure=0.1 bar. Twin leg elevator.

Dust: cornflour ‘B’
Bucket spacing: 280 mm
Igniter positions: level 7 (hood) and part way down the elevator
Vent configurations: vent spacings of 3, 6 and 12 m
Dust loading: 100 kg

The results are summarised in Table 4.

In the tests with the recirculation system, the peak explosion pressures were significantly less than those developed by similar tests using the dust injection system. The lower pressures are likely to be the result of a

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Table 4
Pressures from explosions using recycling system: twin leg elevator

Dust	Vent covers blanked off	Ignition location	Peak pressures (mbar)				Comments
			Boot	Upleg	Downleg	Head	
Cornflour ‘A’	levels 2, 4, 5, 6	Head	88	100	94	97	No flame seen
Cornflour ‘B’	none	Head	216	129	174	154	Flame propagated into downleg to the boot, then to level 2 and 6 upleg.
Cornflour ‘B’	none	Downleg, 0.5 m from the top	194	85	91	111	Flame propagated into downleg to the boot.
Cornflour ‘B’	none	Head	60	90	140	90	Flame propagated into the downleg to level 3.
Cornflour ‘B’	levels 2, 4, 6	Head	136	135	145	152	Flame propagated into the downleg to level 3 and then to level 3 upleg.
Cornflour ‘B’	levels 2, 4, 6	Downleg, 0.5 from top	142	118	246	92	Flame propagated into the downleg.
Cornflour ‘B’	levels 2, 4, 5, 6	Head	92	356	172	317	Flame propagated into downleg then into upleg

reduction in turbulence and differences in the dust concentration. The comparative data are shown in Table 5.

Generally, the direction of explosion propagation was into the downleg following the direction of the bucket movement and occasionally into the upleg via the boot.

These tests show that continuing the operation of the elevator after the explosion can extend the duration of the explosion compared to when the dust is injected. In one test, secondary explosions and external explosions continued until the operation of the elevator was switched off after approximately 1.5 min. Until the buckets were shut down, their movement continued to feed cornflour to the external flames, perpetuating combustion outside the elevator. Large sustained fireballs, typically 5 m in diameter, were produced in the tests and dust deposits that had settled out on the platforms under the vent openings were ignited.

Table 5
Peak Pressures in the twin leg elevator with different dust cloud formations

Vent spacing	Ignition location	Peak pressure (mbar)	
		Injection system	Recirculation system
3 m	head	519	216
3 m	downleg		194
6 m	head	650	152
6 m	downleg		246
12 m	head	3031	356
12 m	downleg		no ignition of cornflour

3. Discussion

3.1. Single leg elevator

Figs. 5 and 6 provide the information from which the vent spacing for dusts with different K_{St} values can be estimated.

Fig. 9 shows how the total vent area required limiting reduced explosion pressures to 1.0 and 0.5 bar varies with the K_{St} value when the value of P_{stat} is 0.1 and 0.05 bar.

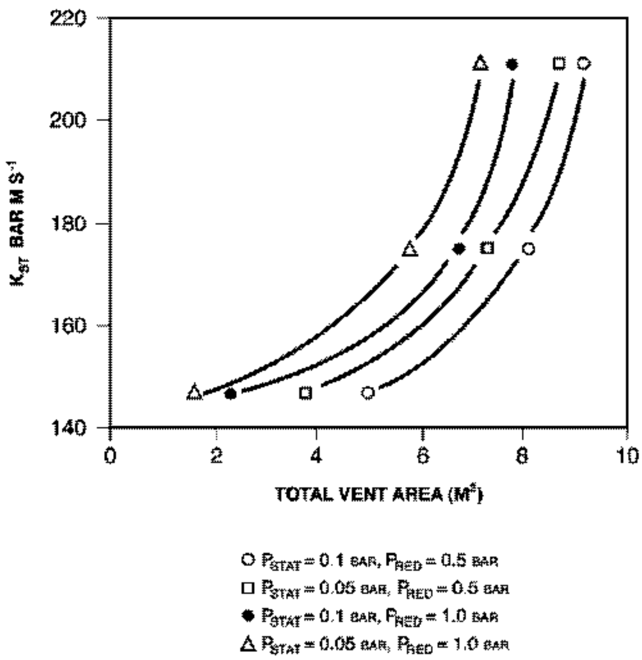

Fig. 9. Total vent area vs K_{St} value. Single leg elevator.

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Table 6
Vent spacing: single leg elevator

K_{St} bar m s^{-1}	P_{stat} bar g	P_{red} bar g	Vent spacing (m)
150	0.05	1.0	19
		0.5	10
	0.10	1.0	14
		0.5	7
175	0.05	1.0	7
		0.5	4
	0.10	1.0	5
		0.5	4
200	0.05	1.0	5
		0.5	3
	0.10	1.0	4
		0.5	3

The vent spacing is calculated by assuming that one vent is positioned in the boot and one in the head of the elevator, and the remaining total vent area is distributed along the elevator assuming each vent has an area equal to the cross-sectional area of the elevator. The vent spacings for several combination values of K_{St}, P_{red} and P_{stat} taken from Fig. 9 are listed in Table 6. The spacing read from Fig. 10 is rounded down to the nearest metre.

The data from the milk powder tests are shown in Fig. 5. In neither of the tests in which venting occurred did the reduced explosion pressure exceed the vent opening pressure, which was 125–135 mbar. In the two tests where venting occurred, the vent nearest the ignition position opened, along with vents approximately 10–12 m from the ignition position. These results indicate that a vent spacing of 14 m will limit reduced explosion pressures to the vent bursting pressure if this is no greater than 0.10 bar.

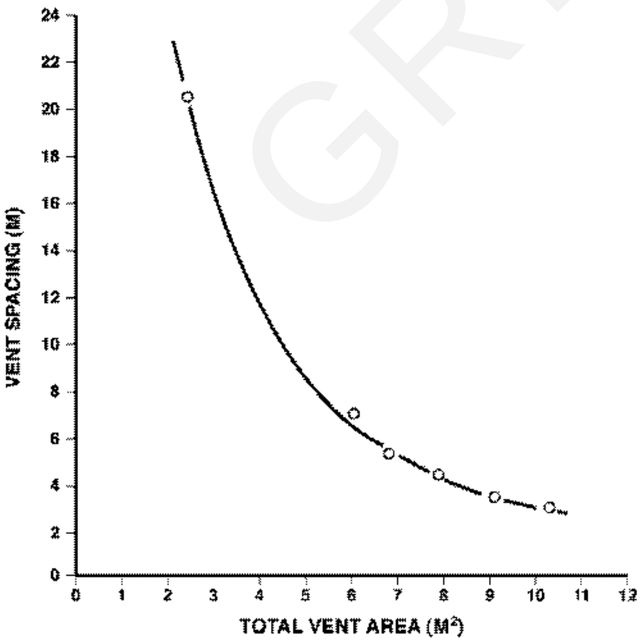

Fig. 10. Vent spacing as a function of total vent area. Single leg elevator.

3.2. Twin leg elevator

The reduced explosion pressure data for bucket spacing of 140 or 280 mm are combined in Fig. 11. This diagram may be used to estimate vent spacing providing:

(i) the vents open at a pressure not exceeding 100 mbar;
(ii) the area of the vent is not less than the cross-sectional area of the elevator leg;
(iii) a vent is positioned at the head and a vent is located as close as possible to the boot.

The data suggest that a vent spacing of 10 m will limit the reduced explosion pressure to 1 bar for dusts with K_{St} values between 150 and 175 bar m s $^{-1}$ and a spacing of 5 m is required for dusts with K_{St} values between 175 and 200 bar m s^{-1}. For dusts with K_{St} values between 100 and 150 bar m s^{-1}, a spacing of 14 m will limit the pressure to 1 bar. For dusts with K_{St} values below 100 bar m s^{-1}, the reduced explosion pressure does not exceed the bursting pressure of the vent cover even at very high vent spacing.

In the early stages of the project, a different twin leg elevator, 17.6 m in height and with buckets spaced at approximately 0.32 m, had been used for some explosion tests with cornflours 'A' and 'B'. Because of its age and atypical installation of buckets, the results from the tests using this elevator have not been used in formulating the guidance. The peak pressures measured in the tests where the explosion propagated through the elevator,

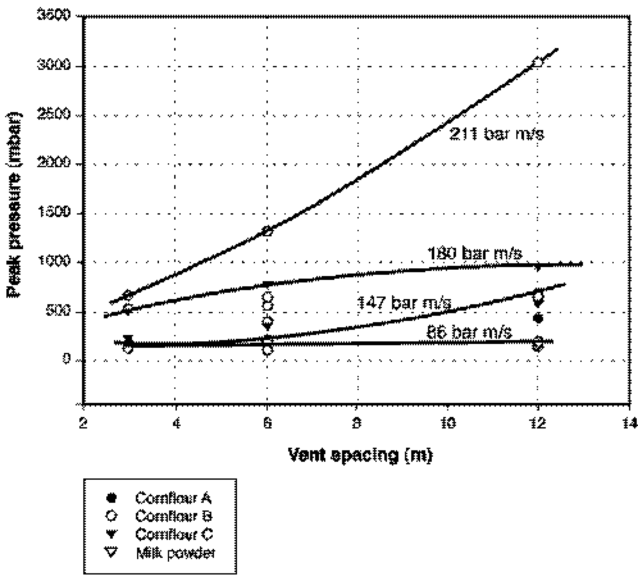

Fig. 11. Explosion pressure vs vent spacing for twin leg elevator. Vent opening pressure=0.1 bar.

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however, are listed in Table 7 along with the vent spacing information. A comparison of these data with the information in Fig. 8 shows that the lines for guidance drawn in Fig. 8 envelop the results from this twin leg elevator.

4. Guidance

4.1. Single leg elevators

Vent openings should have an area equal to the cross-sectional area of the elevator leg and the minimum requirement is that vents should be fitted in the head and as close as is practicable to the boot. This generally means a vent within 6 m of the boot or within the recommended spacing, whichever is the lesser. The spacing between vents along the elevator is listed as a function of the dust K_{St} value, the vent burst pressure and the reduced explosion pressure in Table 6.

For dusts with K_{St} values of 150 bar m s^{-1} or less, a vent spacing of 6 m will limit the reduced explosion pressure to 300 mbar, when the vent static burst pressure is 0.1 bar.

For dusts with K_{St} values of 100 bar m s^{-1} or less, vents installed in the head and boot of the elevator, with none intervening, will limit the reduced explosion pressure to 0.5 bar. For dusts with K_{St} values of 80 bar m s^{-1} or less, a vent spacing of 14 m will limit the reduced explosion pressure to the vent bursting pressure if this is no greater than 0.1 bar.

For dusts with a K_{St} value of 80 bar m s^{-1}, a vent spacing of 20 m will limit the reduced explosion pressure to 250 mbar.

4.2. Twin leg elevators

Vent openings should have area equal to the cross-section of the elevator leg and the least requirement is that vents should be fitted in the head and as close as is practicable to the boot. This generally means within 6 m of the boot or within the recommended vent spacing, whichever is the lesser. The static burst pressure of the vent closure should not exceed 0.1 bar.

The spacing of additional vents depends on the K_{St} value of the dust.

(a) Although explosions are possible with dusts of low K_{St}, generally the pressures developed by dusts with K_{St} values below 100 bar m s^{-1} are not significant, and no additional vents are required.
(b) Dusts with a K_{St} value of 150 bar m s^{-1} are able to develop significant pressures, although the likelihood of explosion propagation through the elevator is low. Vents additional to those at the head and boot may be required on long elevators if the casing is comparatively weak. The graphs in Figs. 7, 8 and 11 should be used to estimate the reduced explosion pressure for a given K_{St} value and vent spacing.
(c) Dusts with K_{St} values above 150 bar m s^{-1} will propagate explosions, and vents additional to those in the head and boot are required on elevators taller than 6 m. The graphs in Figs. 7, 8 and 11 should be used to estimate the reduced explosion pressure for a given K_{St} value and vent spacing. The strength of the elevator should then be designed appropriately.
(d) No data are available for dusts with K_{St} values greater than 210 bar m s^{-1}.

The guidance given in this section differs to that given in NFPA-91 in some important respects. In this guidance the area of a vent is assumed to be equal in cross-sectional area to the leg in which it is installed; in NFPA-91 a vent is assumed to have an area equal to 4/3 of the cross-sectional area of the leg. NFPA-91 suggests the vent area at a given position be divided into two equal vents installed in opposite sides of the leg; the present tests did not, however, show reaction forces to be

Table 7
Peak pressures in early tests with a twin leg elevator

Dust	Vent spacing (m)	Explosion pressure (mbar)	Location of pressure peak
Cornflour ‘A’	average of 2.5 m	231	Boot
Cornflour ‘B’	average of 2.5 m	122	Level 5 upleg
Cornflour ‘B’	average of 2.5 m	202	Level 4 upleg
Cornflour ‘B’	average of 2.5 m	212	Level 6 upleg
Cornflour ‘B’	average of 2.5 m	333	Level 3 upleg
Cornflour ‘B’	average of 2.5 m	430	Level 6 upleg
Cornflour ‘B’	average of 2.5 m	439	Level 4 upleg
Cornflour ‘B’	3.8 m in middle of leg; 2.5 m elsewhere	599	Level 4 downleg
Cornflour ‘B’	3.8 m in middle of leg; 2.5 m elsewhere	797	Level 3 upleg
Cornflour ‘B’	4.41 m at bottom; 2.7 m in middle of leg; 5.29 m at top	581	Level 5 downleg
Cornflour ‘B’	4.41 m at bottom; 2.7 m in middle of leg; 5.29 m at top	466	Boot
Cornflour ‘B’	4.41 m at bottom; 5.43 m in middle of leg; 5.29 m at top	566	Level 4 upleg
Cornflour ‘B’	4.41 m at bottom; 5.43 m in middle of leg; 5.29 m at top	589	Level 5 downleg

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important. NFPA-91 suggests that when the belt speed is below 2.5 m s^{-1} and the capacity is less than 106 m^3 h^{-1} explosion venting is not required; the present results show, however, that belt speed has no noticeable effect on the reduced explosion pressure.

It is essential that the elevator stop quickly in the event of an explosion and this may be achieved by trip switches on vent panels, but because of uncertainty as to which panels may open, a trip on a single panel is not likely to be reliable. A sensitive pressure switch, or switches, or trips fitted to more than one panel are recommended.

Vents should not open into regularly occupied areas, and wherever possible should be either ducted to the outside or fitted with a flameless venting device.

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