EXPLOSION VENTING OF BUCKET ELEVATORS

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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.

INTRODUCTION

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 up-leg of the elevator. The finer materials is likely to remain in suspension, while the coarser material falls back to the boot. At the top of the elevator, while most of the powder will discharge down the off-take chute, some will inevitably be carried over, into the down leg 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[1].

There is, however, no evidence that this guidance spells out the optimum venting requirements of elevators, and there is little published work on elevator explosion tests. Gillis and Fishlock[2] carried out venting and suppression experiments on a twin leg elevator and some guidance was given.

The current project was a collaborative effort by the Health and Safety Executive and manufacturers and users of bucket elevators through the British Materials Handling Board.

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.

SINGLE LEG ELEVATOR

A schematic diagram of the elevator is shown in Figure 1. The single leg steel casing is

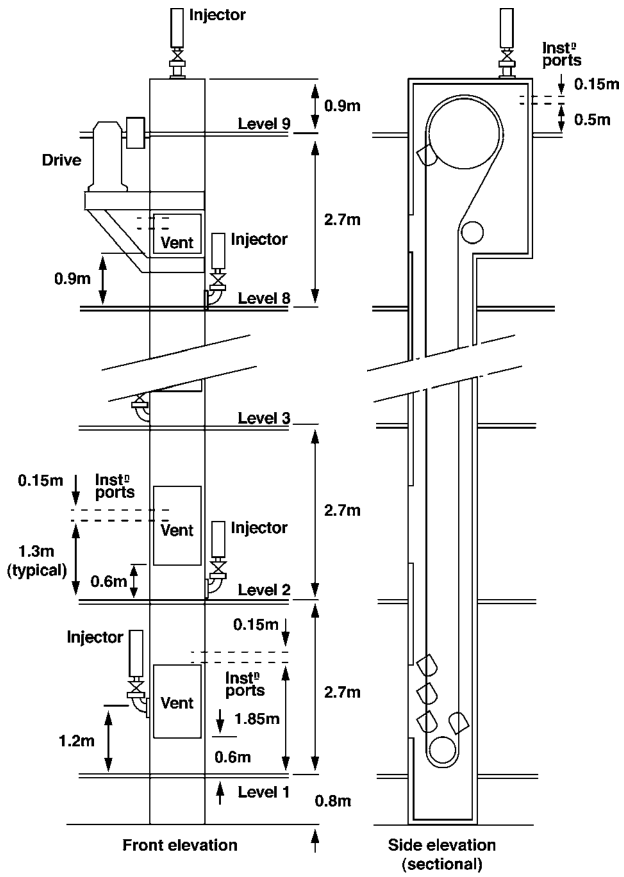


Figure 1 Single leg bucket elevator

rectangular in shape, with a cross section of 1.22 m x 0.945 m in which the chain linked buckets of nominal dimensions 540 mm wide x 280 mm x 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 x 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 x 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. An ignition source could be fitted at level 1, level 5 or level 9 (see Figure 1).

TWIN LEG ELEVATOR

The twin-leg elevator (Figure 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 enable it to withstand the high explosion pressures. The

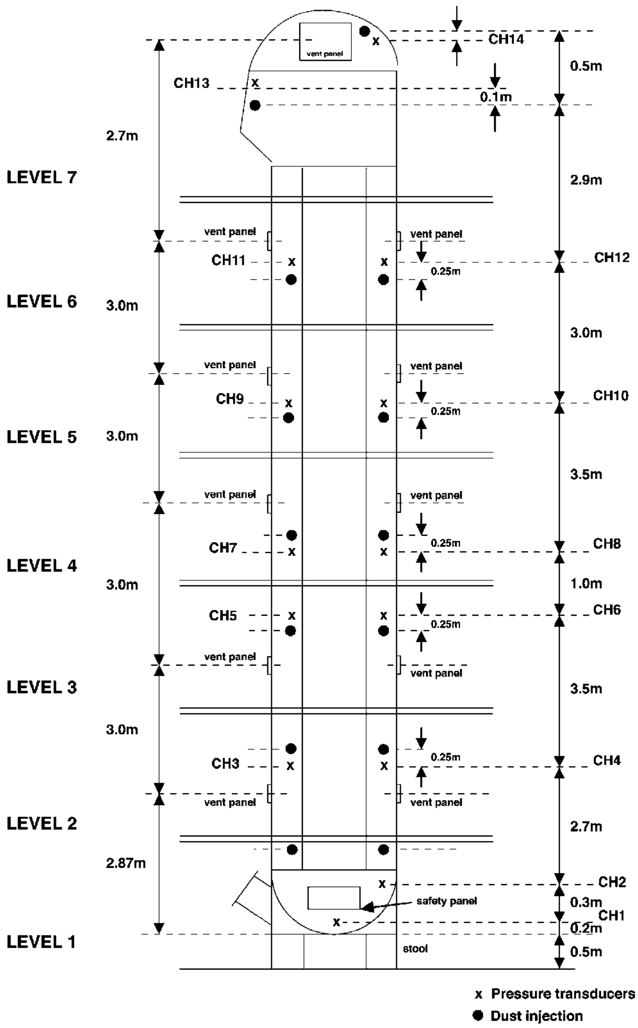


Figure2 Twin leg bucket elevator

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 x 175 mm deep x 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 x 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. The cleaning door at the boot was modified to incorporate a safety panel designed protect the boot in the event of excessive pressure. This was covered with a strong burst panel having 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 x 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 Figure 2).

THE DUSTS

Four dusts have been used in the tests:

Milk Powder: K_{St} = 86 bar m s^{-1}, P_{max} = 7.4 bar g
Cornflour A: K_{St} = 144 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

EXPERIMENTAL RESULTS

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.

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 causes of this are the congested elevator head with buckets, drive and deflection pulley wheels all mounted in close proximity – these would tend to cause restriction to the venting of the explosion and possibly enhanced turbulence.

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.

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 are stationary.

Measurements of Reduced Explosion Pressure

a) Cornflour B

Figure 3 shows all relevant test results using Cornflour B, with the reduced explosion

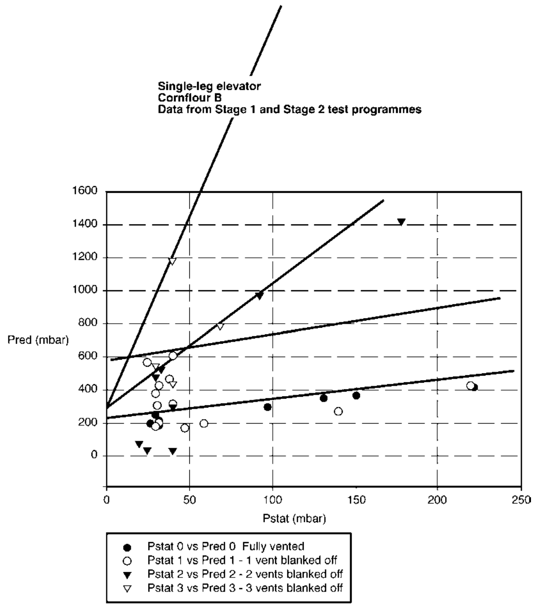


Figure 3 Reduced explosion pressure vs vent bursting pressure

pressure plotted against the vent opening pressure, P_{stat}. 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 a P_{stat} of 0.1 bar has been estimated, and these pressures are plotted in Figure 4 against the total vent area. Similarly in Figure 5, reduced explosion pressures when P_{stat} equals 0.05 bar are plotted against total vent area. The total vent areas necessary to limit the reduced explosion pressure to either 0.5 bar g or 1 bar g have been marked on Figures 4 and 5.

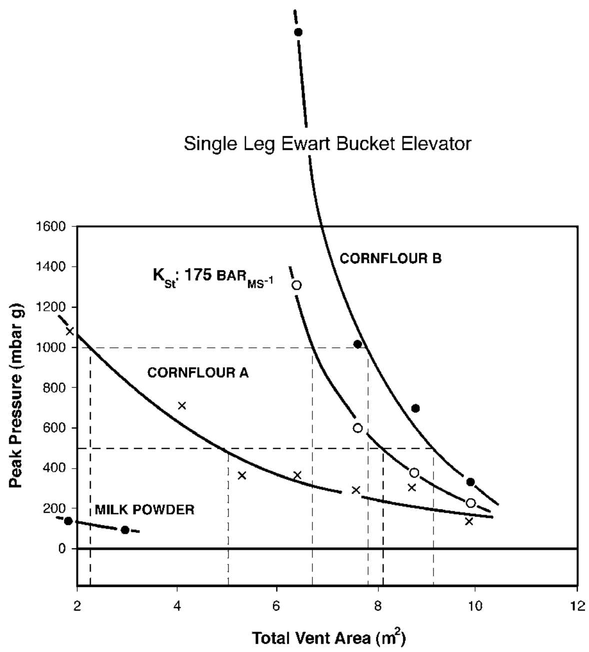


Figure 4 Explosion pressure vs total vent area at a vent opening pressure of 0.1 bar

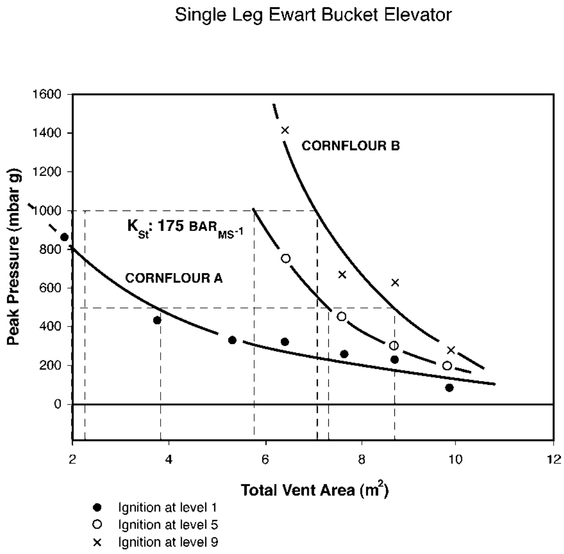


Figure 5 Explosion pressure vs total vent area at a vent bursting pressure of 0.05 bar.

b) Cornflour A

Figure 6 shows all relevant test results using Cornflour A. The points for different total vent

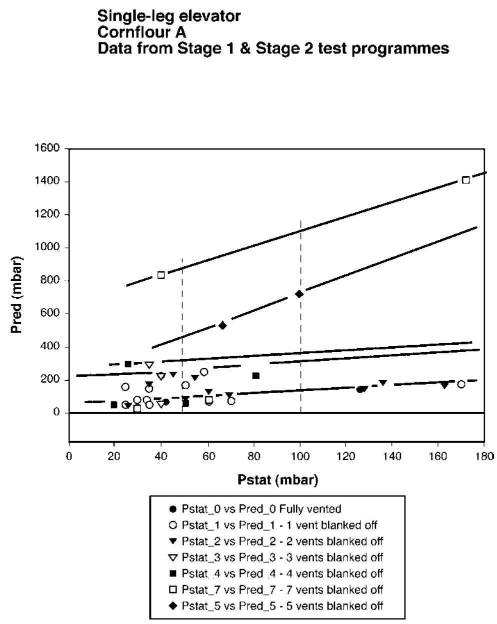


Figure 6 Reduced explosion pressure vs vent opening pressure

areas have been enveloped by straight lines. From each of these lines, upper values of the reduced explosion pressure have been estimated at P_{stat} values of 0.1 bar and 0.05 bar, and are plotted against vent area on Figures 4 and 5 respectively.

c) 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. These results are plotted in Figure 4.

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. Figure 7 shows a cornflour

Figure 7 Cornflour explosion in single leg elevator

explosion that has moved from top to bottom of this elevator and has vented at every level. In a twin-leg elevator, however, the space around and between the buckets is much more limited and it is unclear, at first sight, whether the buckets act as turbulence induces in the flow ahead of the flame and thus cause the explosion to accelerate or act as obstacles to the 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.

Effect of ignition location

Without buckets installed, with the vents at 3 m intervals (fully vented) and using cornflour "A" the most effective location of the ignition source was at the head; with cornflour "B" it was found that the most effective location was at the boot. However, with buckets 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 would allow maximum development of the primary explosion prior to the expanding flames making contact with the elevator walls and buckets.

Effect of bucket spacing – fully vented elevator

Tests were carried out initially without the 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 with a vent at the head. A range of ignition locations was used.

Table 1 demonstrates the progressive increase in explosion pressure with increased numbers of buckets in the elevator with cornflour "B". However, with cornflour "A" the buckets tended to inhibit flame propagation with accompanying low pressures.

Table 1. Peak explosion pressures – fully vented 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

Without the buckets installed, both cornflour "A" and "B" propagated flame through the elevator. The more reactive dust, Cornflour "B", produced a slightly higher peak pressure (211 mbar) compared with 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" flame 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" still propagated through the elevator with the explosion pressure increased further to 314 mbar. This provides evidence that the presence of the buckets increased the turbulence in the case of cornflour "B" but the buckets inhibit flame propagation with cornflour "A" although this was not always the case.

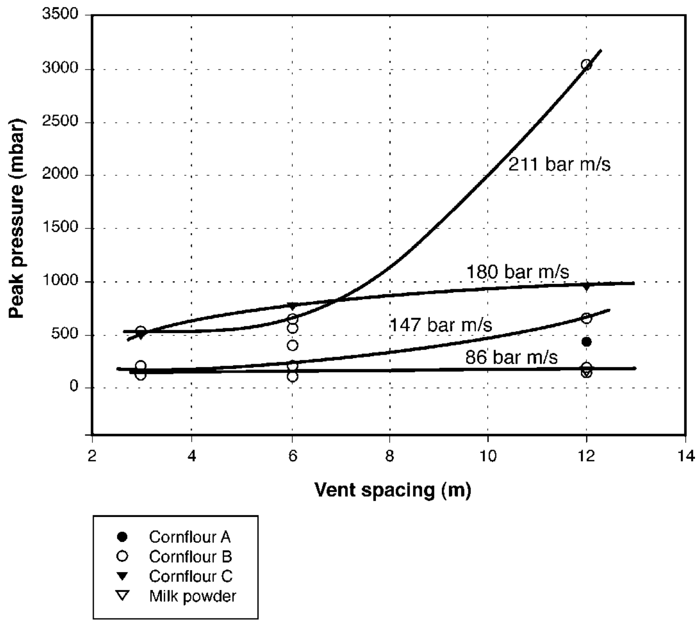
In one test with 1 m spacing of the buckets and the elevator running, with ignition at the head and using cornflour "A", flame propagated past the buckets from the head to the boot after which is propagated up the downleg and produced 273 mbar at the boot – a pressure comparable with cornflour "B" which produced 265 mbar in a nominally identical test.

Explosion tests with varied vent configurations

The peak explosion pressures were measured for a range of vent configurations using four dusts. The buckets were running in all the tests.

Pressure data from the tests with the buckets spaced at 280 mm and 140 mm have been plotted and are presented in Figures 8 and 9 respectively.

Vent spacing was set at 3 m, 6 m and 12m. 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

Figure 8 Explosion pressure vs vent spacing. Buckets at 280 mm spacing; Vent opening pressure = 0.1 bar.

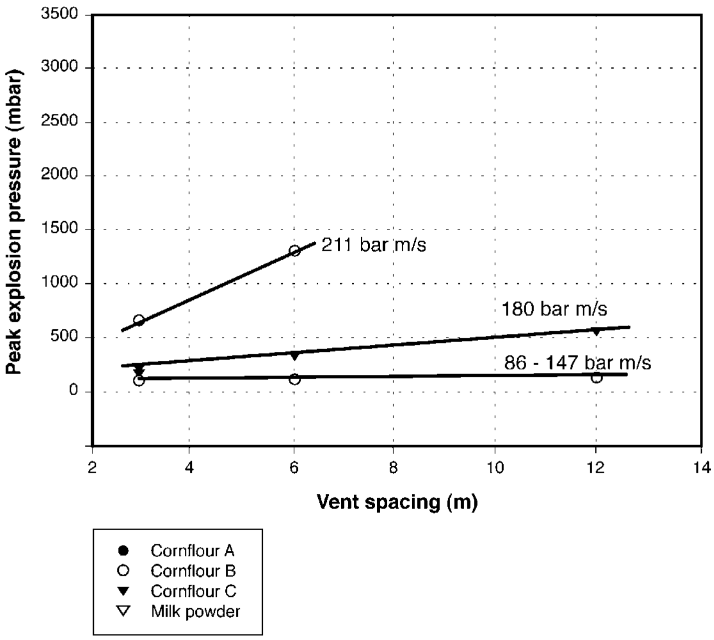


Figure 9 Explosion pressure vs vent spacing. Buckets at 140 mm spacing; Vent opening pressure = 0.1 bar.

propagated into the upleg to the boot and into the downleg. In one test, with a vent spacing of 6m, 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. Secondary flame then re-emerged at level 5 in the downleg and persisted for approximately 4 seconds at the vent after which 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.

Tests with the Recycle system

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

The elevator was cleaned internally and the appropriate vent configuration was installed. Cornflour was manually loaded into the elevator boot and the elevator was run for approximately 3 – 4 minutes 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

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

In the tests with the recirculation system in use, the peak explosion pressures were significantly less than those developed by similar tests but using the dust injection system. The lower pressures are likely to be the result of a reduction in turbulence and differences in the dust concentration. The comparative data is shown in Table 2.

Table 2. 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

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 continueing 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 minutes. 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 5m in diameter, were produced in the tests and dust settled out on the platforms under the vent openings were ignited.

DISCUSSION

SINGLE LEG ELEVATOR

Figures 4 and 5 provide the information from which the vent spacing for dusts with different K_{St} values can be estimated. A linear interpolation has been used to estimate reduced explosion pressures for a K_{St} – value of 175 bar m s^{-1}.

Figure 10 shows how the total vent area required to limit reduced explosion pressures to 1.0 bar and 0.5 bar varies with the K_{St} – value when the value of P_{stat} is 0.1 bar and 0.05 bar.

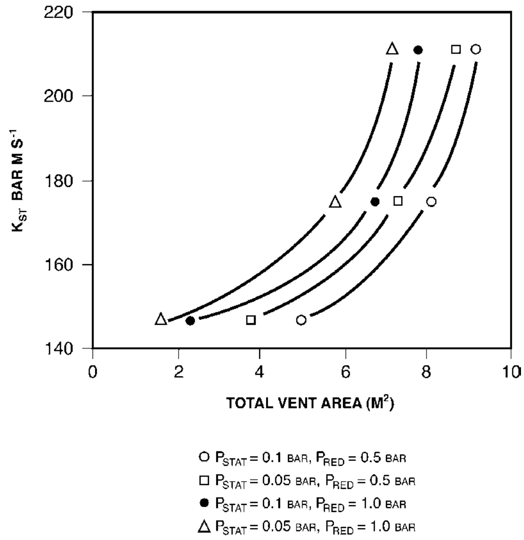


Figure 10 Total vent area vs K_{St} value. Single leg elevator

The relationship between total vent area and vent spacing is shown in Figure 11. The

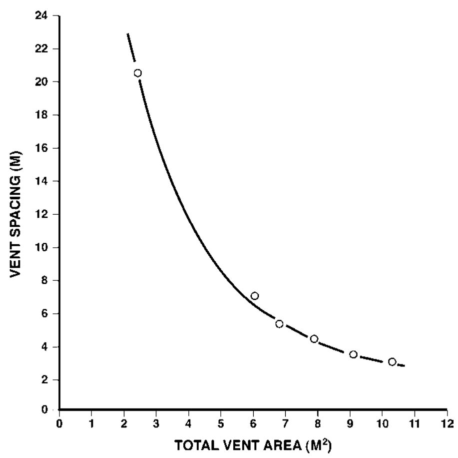


Figure 11 Vent spacing as a function of total vent area. Single leg elevator.

vent spacing is calculated by positioning one vent in the boot and one in the head of the elevator, and distributing the remaining total vent area along the elevator assuming each vent has an area equal to the cross-sectional area of the elevator. The vent spacing for several values of K_{St} and P_{stat} are listed in Table 3. The spacing read from Figure 11 is rounded down to the nearest metre.

Table 3. Vent Spacing

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 data from the milk powder tests is shown on Figure 4. In neither of the tests which vented 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. It is recommended that a spacing of 10 m will, for dusts of K_{St} equal to 100 bar m s^{-1} limit reduced explosion pressures to the vent bursting pressure if this is no greater than 0.10 bar.

By comparison with the data from other dusts, vents fitted in the boot and head of an elevator will limit the pressures to less than 0.5 bar g for dusts with K_{St} – values of 100 bar m s^{-1} or less.

TWIN LEG ELEVATOR

The reduced explosion pressure data for bucket spacing of 140 mm or 280 mm are combined in Figure 12. 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 10m 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 5m 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 14m will limit the pressure to 1 bar.

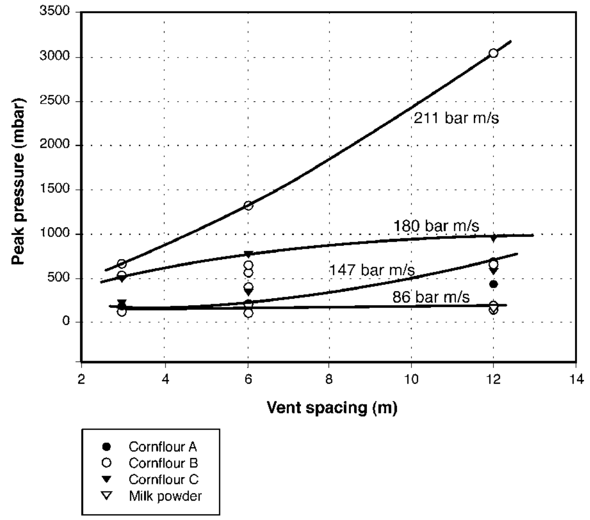


Figure 12 Explosion pressure vs vent spacing for twin leg elevator. Vent opening pressure = 0.1 bar.

GUIDANCE

SINGLE LEG ELEVATORS

Vent openings should have an area equal to the cross-sectional area 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 a vent within 6m 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 3.

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

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

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 6m 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 Figures 8, 9 and 12 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 6m. The graphs in Figures 8, 9 and 12 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 is available for dusts with K_{St} values greater than 210 bar m s^{-1}.

It is essential that the elevator stop quickly in the event of an explosion. 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. Either 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 device that prevents flames emerging (e.g. a Q pipe).

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1. Lunn, Geoff. Guide to Dust Explosion Prevention and Protection. Part 1 – Venting (2nd Edition) Institute of Chemical Engineers, Rugby (1992).

2. Gillis, J.P. and Fishlock, F.H. Explosion Venting and Suppression of Bucket Elevators.

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