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THE VENTING OF DUST EXPLOSIONS IN A DUST COLLECTOR

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Summary

Pressures generated by dust explosions in a commercial dust collector have been measured. The dust clouds were formed while the collector was operating under normal working conditions, i.e. dusts were dislodged from the filter elements inside the collector by pulsed reversed air jets. The vented explosion pressures measured under these conditions provide a realistic guide to the explosion pressures that the filter may have to withstand in practice. These pressures are low (2 kPa) when the explosion is vented through a vent close to the ignition source. If, however, the vent is remote from the ignition source and flame turbulence is generated, the rate of combustion is increased and the explosion pressures are higher (14 kPa). The vented explosion pressures encountered when the flame becomes turbulent are reasonably well predicted by the K_{st} nomograph approach. Pressures generated by highly turbulent explosions in a silo-shaped container have also been compared to the K_{st} nomograph predictions. In these experiments, the pressures were always much higher than predicted.

Introduction

Many dusts commonly encountered in industry will explode if their concentrations, when dispersed in air, are within the explosible concentration range and an ignition source is present. An explosion in an unprotected piece of industrial equipment can be destructive and it is common practice to use explosion vents on equipment such as dust collectors so that internal explosion pressures are kept low.

The area of relief vent necessary to limit the explosion pressure to a predetermined value can be calculated by several methods, one of the most popular being the K_{st} nomograph method [1]. Dust explosions are, however, difficult to characterise and there is doubt about whether results from controlled laboratory experiments can be applied sensibly to dust explosions in a working piece of industrial equipment. Factors such as turbulence, dispersion of the dust, and the volume occupied by a flammable mixture can radically alter the progress of a dust explosion. Although well defined in laboratory scale experiments, the role of these factors is uncertain in explosions that take place in practical, industrial equipment.

In spite of this, reliance is still placed on "worst case" assessments of the venting requirements even when the real situation might not warrant it. For instance, the nomographs used in the K_{st} method are based on tests with a dust of small particle size well dispersed in high turbulence throughout the entire volume and then ignited by a high energy ignition source. In some industrial cases these conditions may appertain, but in others they most certainly do not.

This paper reports measured overpressures generated by dust explosions inside a commercial dust collector that is operating as it would in a normal industrial environment. Although the major objective of the experiments was to test the ability of the collector to withstand the explosions without damage, they provide an opportunity to asess the applicability of current predictive methods to industrial equipment. The measured explosion pressures have been compared therefore to the pressures predicted by the K_{st} nomograph method. In addition, pressures generated by explosions of dust clouds injected into the collector have been compared to predicted values. In a further series of experiments, pressures generated by turbulent dust explosions ignited in a 1.2-m diameter steel tube were measured and then compared to the K_{st} predictions.

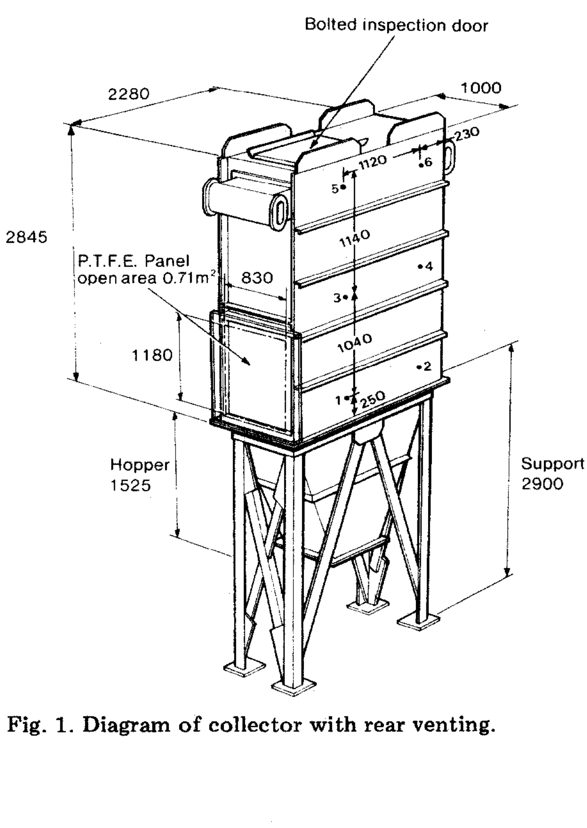

Fig. 1. Diagram of collector with rear venting.

Apparatus, equipment and experimental

The dust collector

The dust collector is a typical production model and is shown in Figs. 1 and 2. Figure 1 shows the collector fitted with a back relief vent, and Fig. 2 with a top relief vent. The dimensions of the collector are given in the figures. A photograph of the collector and associated pipe-work constructed for the tests is shown in Fig. 3. The dust inlet is the entry on the near side of the collector as shown in Fig. 3, the dust being drawn along the pipework from the hopper at the right. The dust-laden air is directed downward onto the filter elements in the collector. The air passes through the fabric into the insert header on the "clean" side of the collector and is then discharged through the outlet on the far side of the collector as shown in Fig. 3. The collector incorporates four filter modules. Each module comprises ten flat, rectangular filter elements 1.5 m long and inserted through parallel slots in a frame dividing the dust side from the clean side. Cleaning of the fabric filters is done by pulses of compressed air in a direction opposite to the normal air flow (reverse pulses), using an electronic timer to activate a series of pilot valves in sequence at predetermined intervals on a continuous cycle. In this way the filters are cleaned without interrupting the operation of the collector. Each pulse dislodges the dust

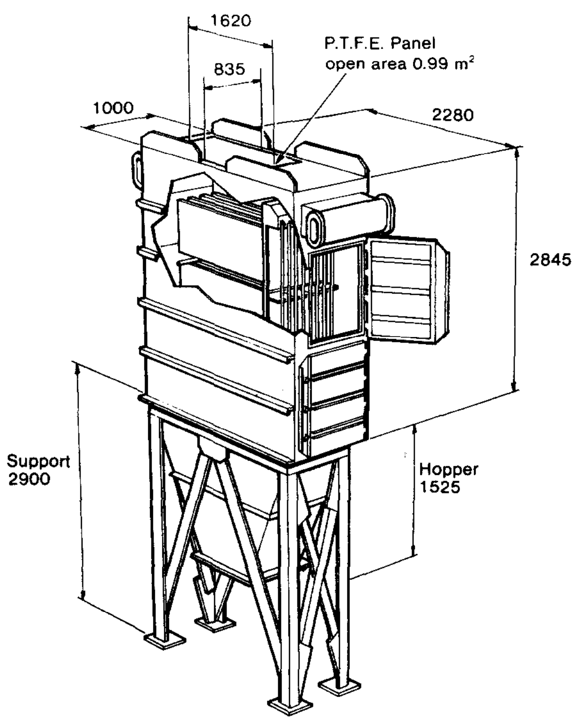

Fig. 2. Diagram of collector showing top venting.

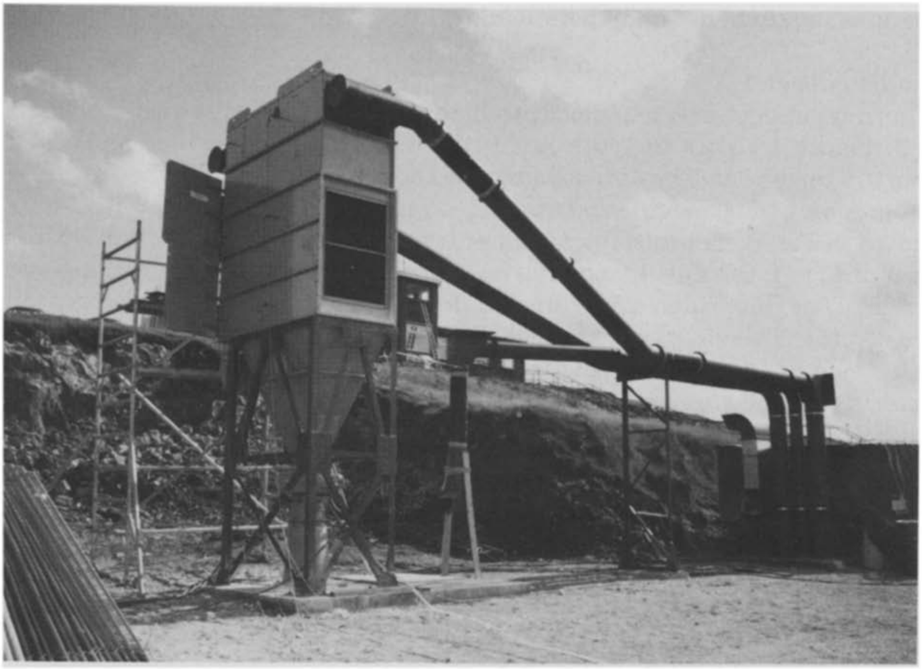

Fig. 3. Collector.

from four of the filter bags. In normal working a pulse occurs every 12 seconds. For a typical experiment dust was fed into the collector in a controlled manner and an estimate of the amount of dust collected on the bags obtained by measuring the back pressure across the filter bags. During this period the reverse-pulse jet mechanism was not activated.

When the required back pressure was obtained, the pulse jet mechanism was switched on, at a rate of one pulse every three seconds. Because of the cyclic nature of the process the concentration of dispersed dust varies with time, a flammable cloud being more likely to exist just after a jet pulse than in the few seconds before it. Increasing the rate of pulses tends to smooth out these concentration fluctuations without departing from the sort of concentrations likely to be met in practice.

The ignition source was a 30 g charge of black powder ignited by an electrically ignited fuse. In all the experiments the ignition source was positioned in the hopper beneath the collector. The igniter was fired after the eighth pulse of the reversed air jets. The pressure generated by the ignition source was insufficient to break open the vent panel, and was less than 1 kPa. As can be seen from the pressure–time curves in the figures, the pressure pulse from the igniter is well separated from the pressure rise caused by the dust explosion.

Six pressure recordings were taken in each test. The positions of the pressure transducers, three on the "dusty" side and three on the "clean" side, are shown in Fig. 1. The vents were covered with a PTFE membrane (0.2 mm thickness) which had a nominal static bursting pressure of 10 kPa. The total free area of the top vent was 0.99 m^2 and that of the rear vent was 0.71 m^2. The total volume of the collector was 6.73 m^3. The "dust side" volume was 4.23 m^3, the "clean side" volume was 1.36 m^3 and the free volume of the hopper was 1.14 m^3, making a maximum volume into which the dust can initially be dispersed of 5.37 m^3.

The filter bags were renewed prior to each test.

The 1.2-m diameter steel gallery

The 1.2-m diameter steel gallery is shown in Fig. 4. The gallery is circular in cross section and is 7.6 m long. Dust is blown into the gallery through a 25-mm diameter port in the centre of the closed end, a known amount of dust being injected from an external pressure vessel at a pressure of 545 kPa. A discrete ignition source fired at a specified delay after the start of dust was fixed 3 m from the closed end on the axis of the gallery. In these tests a charge of 30 g of black powder ignited by a fuse-head was used as the ignition source. Pressure transducers were positioned along the gallery; transducer 1 at 2 m, transducer 2 at 5 m and transducer 3 at 7 m from the closed end.

Fig. 4. The 1.2-m diameter steel gallery.

The dust collector with injector apparatus

For a series of tests in which an artificially created dust cloud was ignited inside the collector the injection system from the 1.2-m steel gallery was used. The ignition source was positioned in the hopper, and top venting used in all these tests. The dust cloud was injected into the hopper at approximately 45° to the horizontal to ensure that there was adequate dispersion throughout the body of the equipment. Clean filter bags were used in these experiments.

The dusts

Four dusts were used in these experiments — polyethylene, phenolic resin, toner and aspirin. The explosibility properties of these dusts were measured by the standard 20-l sphere method [1].

Polyethylene

The sample had a moisture content of 0.2% and the particle size distribution is given in Table 1. The explosibility test results are given in Table 2.

TABLE 1

Particle size analysis (polyethylene)

Particle size fraction (μm)	Weight (%)
<10	1.7
>10 <20	70.7
>20 <36	27.6

TABLE 2

Maximum rates of pressure rise in 20-l sphere: polyethylene dust

Dust concentration (kg/m³)	Maximum explosion pressure (bar)	Maximum rate of pressure rise (bar/s)	K_{st} (bar m/s)
0.25	6.75	410	111
0.50	7.21	508	138
0.75	6.21	434	118
1.00	5.76	441	120
2.00	4.38	266	72

Phenolic resin

The sample had a moisture content of 3.0% and the particle size distribution is given in Table 3. The explosibility test results are given in Table 4.

TABLE 3

Particle size analysis (phenolic resin)

Particle size fraction (μm)	Weight (%)
<36	28.6
>36 <56	8.4
>56 <90	7.7
>90 <160	21.3
<160	34.0

TABLE 4

Maximum rates of pressure rise in 20-l sphere: phenolic resin

Dust concentration (kg/m^3)	Maximum explosion pressure (bar)	Maximum rate of pressure rise (bar/s)	K_{st} (bar m/s)
0.25	4.30	66	18
0.50	6.29	119	32
0.75	6.67	267	72
1.00	6.33	302	82
1.50	6.25	387	105
2.00	5.95	471	128
3.00	5.37	516	140
5.00	4.15	333	90

TABLE 5

Particle size analysis (toner dust)

Particle size fraction (μm)	Weight (%)
<10	9.7
>10 <20	90.3

TABLE 6

Maximum rates of pressure rise in 20-l sphere: toner dust

Dust concentration (kg/m^3)	Maximum explosion pressure (bar)	Maximum rate of pressure rise (bar/s)	K_{st} (bar m/s)
0.10	5.30	186	50
0.25	7.52	565	153
0.50	7.48	623	169
0.75	6.94	541	147
1.00	6.21	432	117
2.00	4.45	218	59

Toner dust

The sample had a moisture content of 0.7% and the particle size distribution is given in Table 5. The explosibility test results are given in Table 6.

Aspirin dust

The sample had a moisture content of 1.2% and the particle size distribution is given in Table 7. The explosibility test results are given in Table 8.

The K_{st} value is calculated from the 20-l sphere results by means of the cube-root law

$$\left(\frac{dp}{dt}\right)_{max} V^{1/3} = K_{st}$$

where V is the volume of the vessel (m^3) and $(dp/dt)_{max}$ is the maximum rate of pressure rise (bar/s). K_{st} is a constant for a particular dust. Depending on the K_{st} value, a dust can be classified as non-explosible, mildly explosible or very explosible:

$K_{st} = 0$ Explosion Class: St0
$K_{st} > 0$–200 Explosion Class: St1
$K_{st} > 200$–300 Explosion Class: St2
$K_{st} > 300$ Explosion Class: St3

TABLE 7

Particle size analysis (aspirin)

Particle size fraction (μm)	Weight (%)
<20	17.1
>20 <36	22.6
>36 <56	22.7
>56 <90	21.2
>90	16.4

TABLE 8

Maximum rates of pressure rise in 20-l sphere: aspirin dust

Dust concentration (kg/m^3)	Maximum explosion pressure (bar)	Maximum rate of pressure rise (bar/s)	K_{st} (bar m/s)
0.25	4.87	128	35
0.50	6.52	343	93
0.75	7.75	574	156
1.00	7.52	517	140
1.50	7.02	701	190
2.00	6.60	604	164
3.00	5.99	593	161

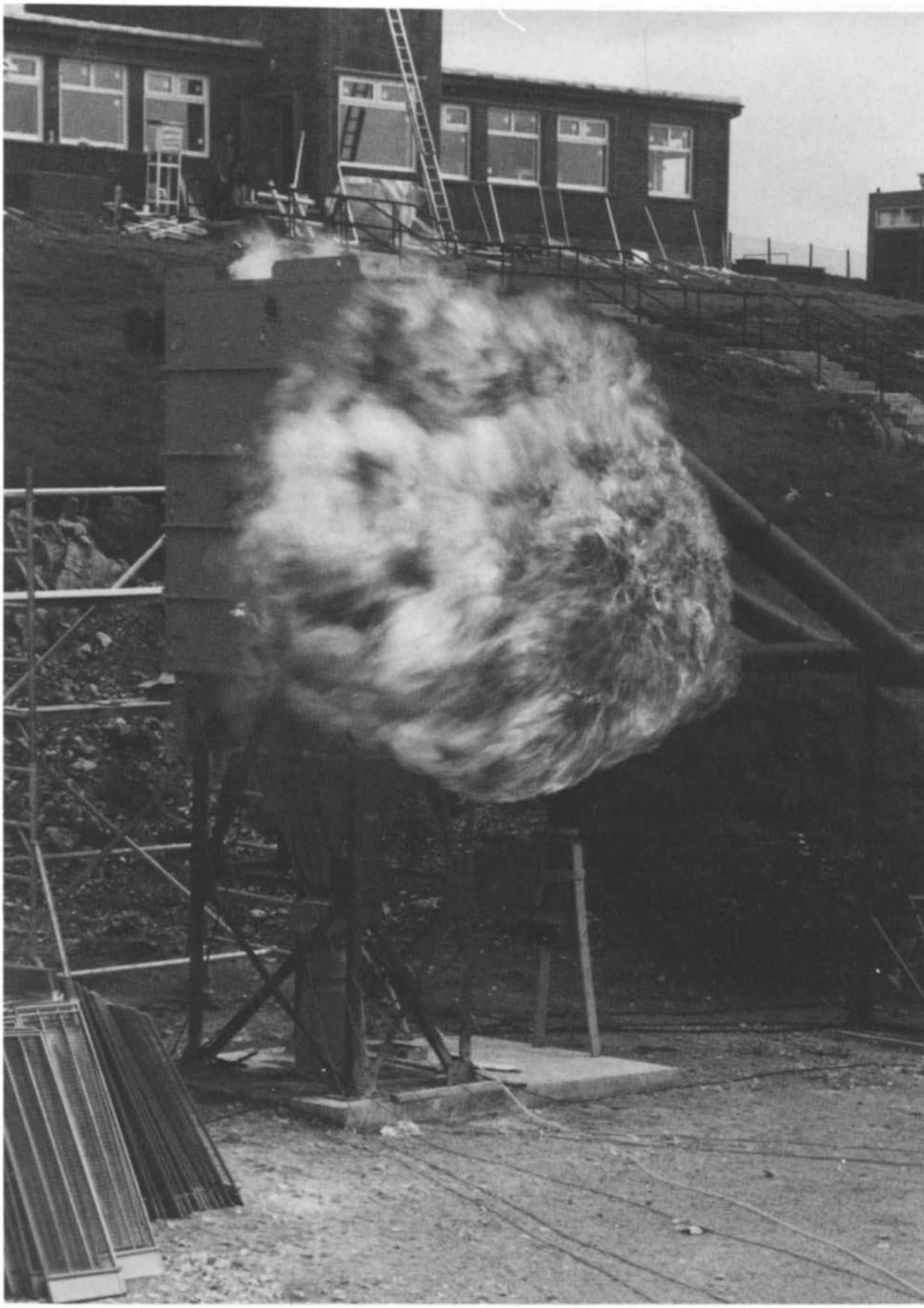

Fig. 5. Rear-vented dust explosion in collector. Phenolic resin powder.

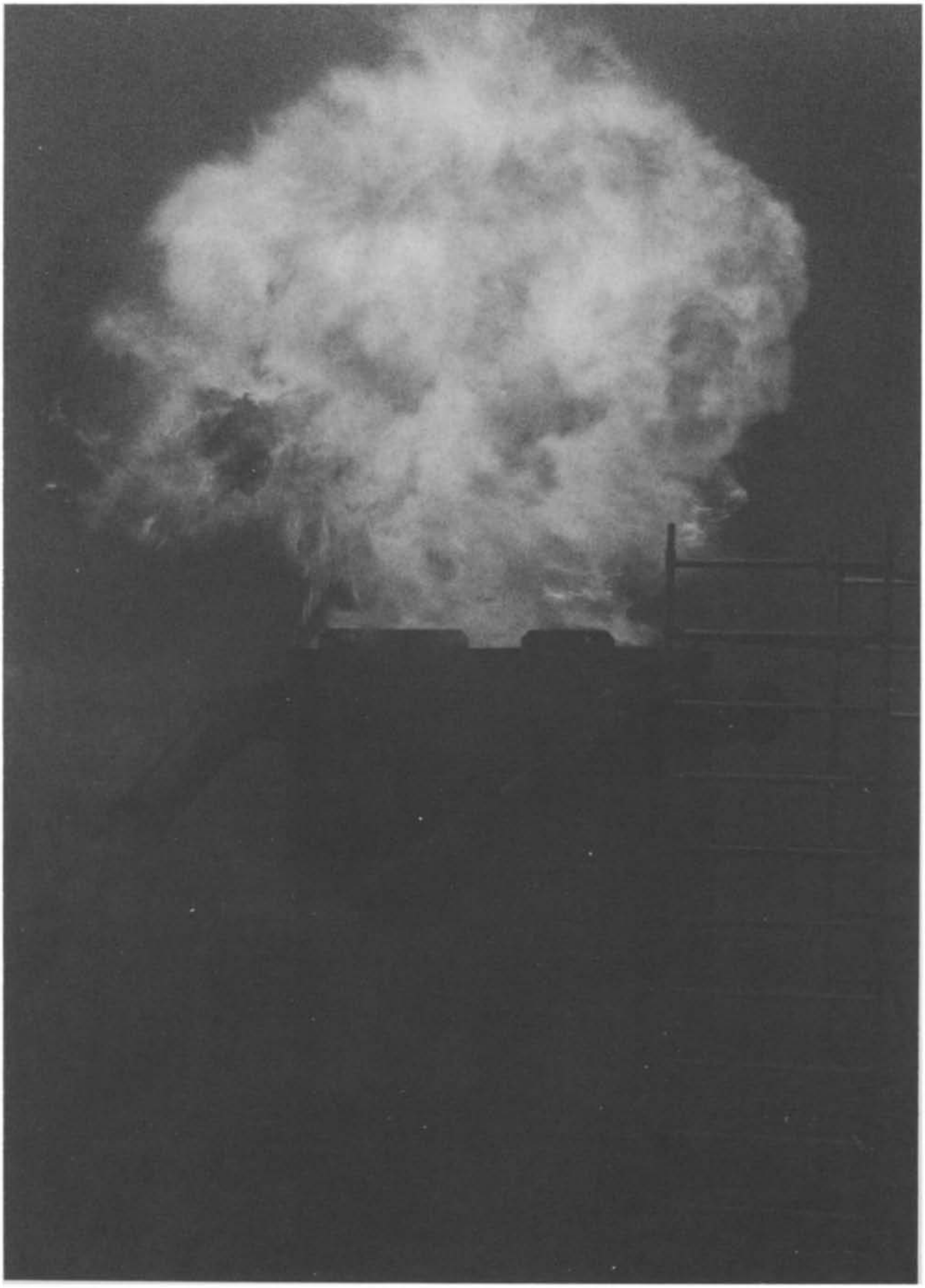

Fig. 6. Top-vented explosion in collector. Toner dust.

The nomograph approach to calculating vent areas is based on K_{st} measurements and this classification [3].

Results

Measurements in the collector

An example of a rear-vented phenolic resin dust explosion is shown in Fig. 5, and an example of a top-vented toner dust explosion is shown in Fig. 6.

Polyethylene dust

In these experiments various amounts of dust deposited on the filter bags were dispersed in the filter. However, only those experiments in which dust dispersal was commenced at back pressures across the filter bags of greater than 2.5″ w.g. produced dust explosions on ignition. It is probable that dust concentrations produced by dispersal of deposits producing back pressures of less than 2.5″ w.g. were below the explosive limit.

With rear venting, tests were done in which the dust was dispersed when the back pressure across the filter bags had reached 2.5, 3, 3.5 and 6″ w.g. The explosions were successfully vented and the explosion pressures did not exceed 2 kPa. In these tests the vent was close to the ignition source and the explosion was vented before turbulence could be generated. These conditions were thus favourable for keeping explosion pressures low.

In the tests with top venting, the vent was remote from the ignition source and the explosion reached the vent only after passing between the racks of filter bags. It is probable that turbulence was generated as the flame passed between the racks and that this turbulence enhanced the rate of combustion and hence the explosion pressure. The pressures were still relatively low, however, no greater than 14 kPa at any point in the collector. Typical pressure traces from three experiments are shown in Figs. 7, 8 and 9. Maximum

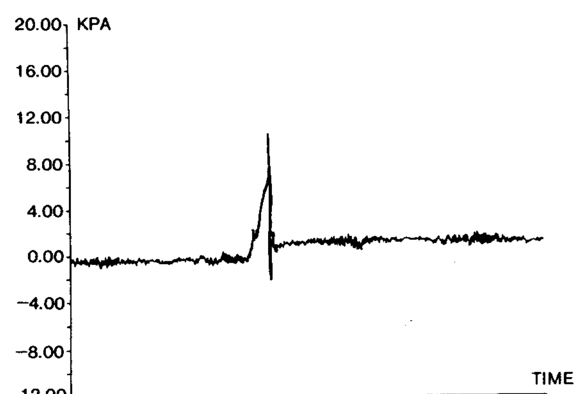

Fig. 7. Pressure trace: top-vented polyethylene dust explosion in collector. Back pressure 3.0″ w.g. Transducer 1.

pressures at different points in the collector were approximately equal in a given test, pressures on the "clean" side of the filter elements being little different from pressures measured on the "dusty" side. The filter elements did not act as a barrier to the pressure generated by the explosion, probably because they were easily punctured by the heat of the flame. However, it is evident from the above results that venting the explosion close to the source

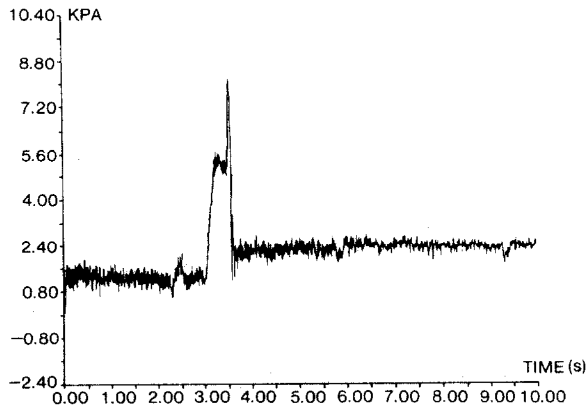

Fig. 8. Pressure trace: top-vented polyethylene dust explosion in collector. Back pressure 4" w.g. Transducer 1.

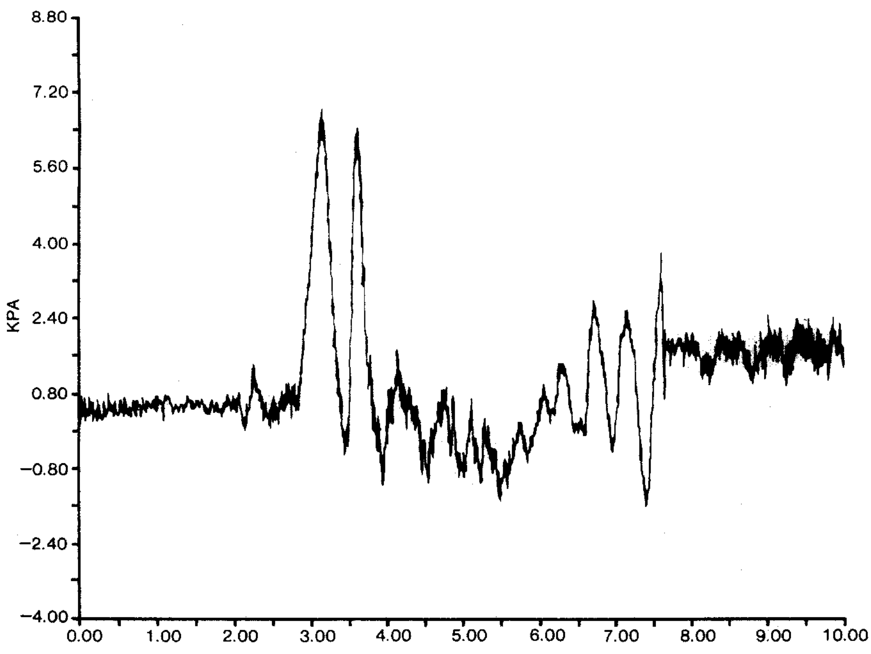

Fig. 9. Pressure trace: top-vented polyethylene dust explosion in collector. Back pressure 5" w.g. Transducer 1.

of ignition (rear venting of the collector) resulted in a significant reduction in explosion pressure.

Figure 9 is a pressure—time profile from an unusual explosion. Instead of the vent opening at an early stage in the explosion, as in all previous tests, the internal explosion was relatively long-lived and the vent cover burst at a late stage, certainly after the explosion had been fed with dust from a succeeding pulse of the reversed air jet. Video recording of the explosion showed that the flame had travelled along the dust inlet ducting and blown the vent there before a further series of pressure pulses and explosions in the filter body occurred, bursting the main top vent. Why the top vent should burst at a late stage in the explosion when pressures are relatively low and not earlier when higher pressures are measured is not known. In this test transducer 4 measured relatively low pressures compared to other positions in the filter.

Toner dust

In an experiment in which reverse air pulsing was commenced at a back pressure of 1.7″ w.g., an explosion overpressure of 9 kPa was recorded. The explosion was vented at the top of the collector. A typical pressure trace is shown in Fig. 10.

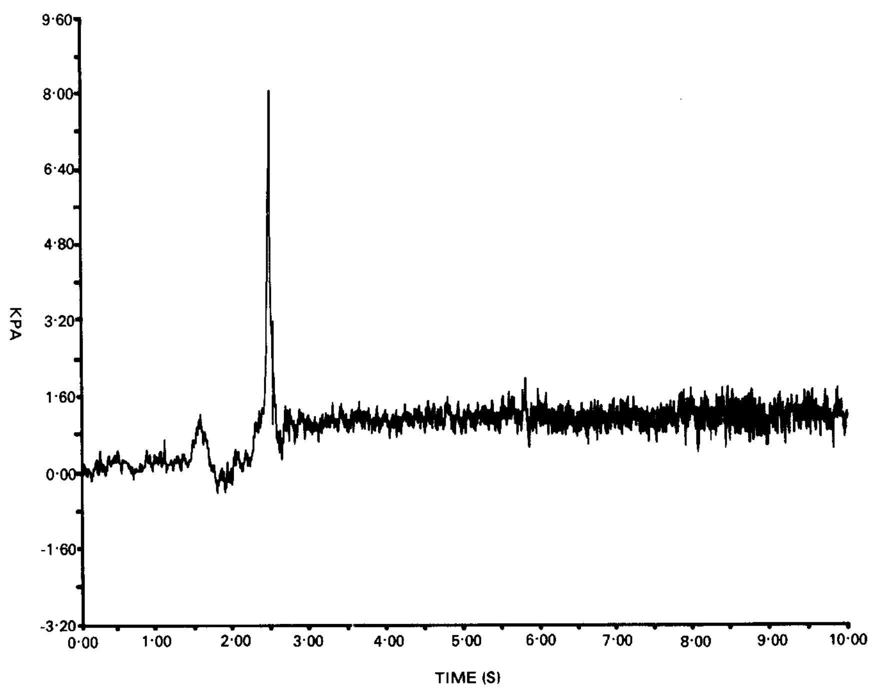

Fig. 10. Pressure trace: top-vented explosion in collector. Toner dust, back pressure 1.7″ w.g. Transducer 1.

Aspirin dust

Pressure traces for aspirin dust explosions are shown in Figs. 11 and 12. Explosion pressures of 14 kPa were not exceeded. Figure 11 is a pressure trace from an unusual explosion. Reversed jet pulses were commenced at a back pressure of 1.8″ w.g., and ignition took place after the fifth pulse. The trace indicates that several internal explosions occurred, the pressure peaks occurring at intervals of 3 seconds, when the explosion was supplied with dust from a pulse of the reversed air jets. The vent burst approximately 7 seconds after ignition.

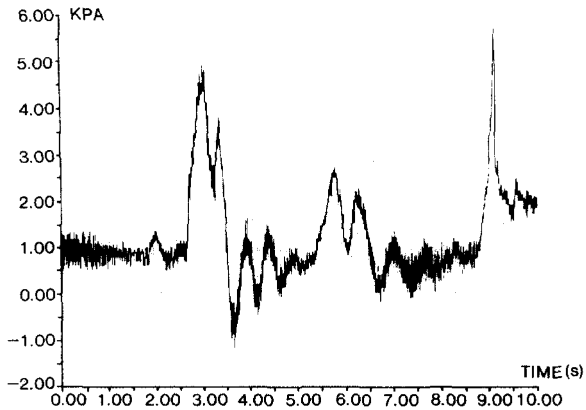

Fig. 11. Pressure trace: top-vented explosion in collector. Aspirin dust, back pressure 1.8″ w.g. Transducer 1.

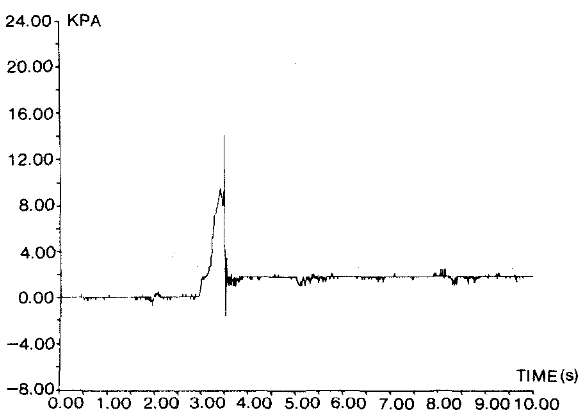

Fig. 12. Pressure trace: top-vented explosion in collector. Aspirin dust, back pressure 1.4″ w.g. Transducer 2.

Experiments with an injected dust cloud

Polyethylene

One and a half kilogrammes of polyethylene dust were injected into the collector and a 30 g black powder ignition source fired 2 seconds after the

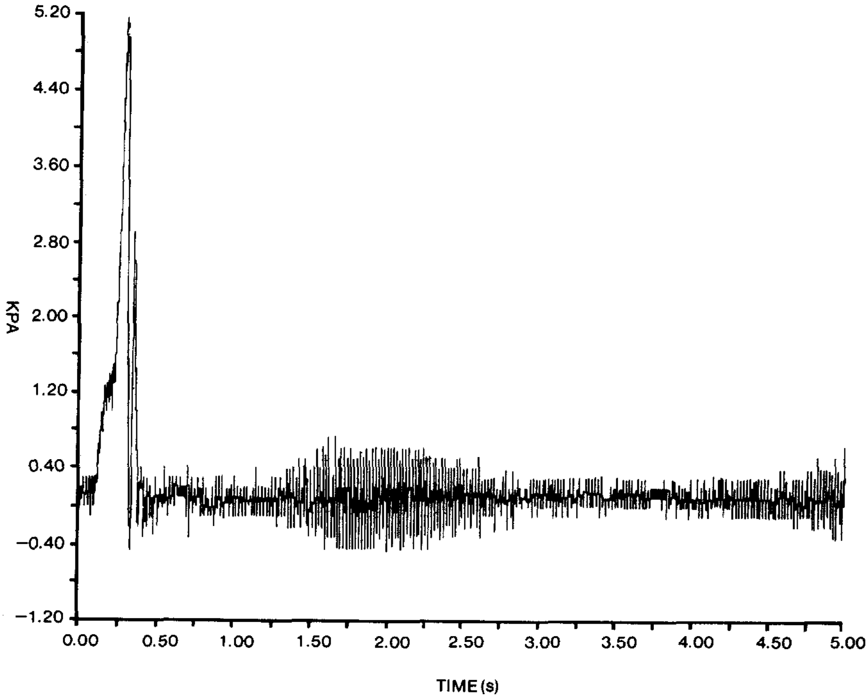

Fig. 13. Pressure trace: top-vented explosion in collector. Polyethylene dust, 1.5 kg, 2 s delay. Transducer 3.

start of injection. A typical pressure trace is shown in Fig. 13. The maximum pressure recorded at all six transducers was 5.2 kPa.

Toner dust

One kilogramme of toner dust was injected into the collector with an ignition delay of 2 seconds. The maximum explosion pressure was 7.2 kPa. A typical pressure trace is shown in Fig. 14.

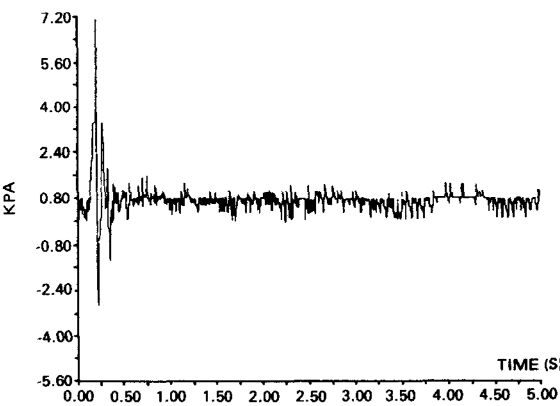

Fig. 14. Pressure trace: top-vented explosion in collector. Injected toner dust, 1.0 kg, 2 s delay. Transducer 6.

Experiments in the 1.2-m steel gallery

The tests in the steel gallery (L/D = 8.3) were designed so that a highly turbulent, well dispersed dust cloud would be formed. The could was ignited at the optimum time to obtain the highest explosion overpressures.

Polyethylene

The maximum pressure recorded in this series of experiment (40 kPa) was obtained using 2.5 kg of injected dust and an ignition delay of 2 seconds following the start of injection. The pressure trace at transducer 1 is shown in Fig. 15 and is typical of all the pressure traces obtained in the gallery experiments. The maximum pressure was a function of position along the gallery. Close to the open end (transducer 3) the maximum pressure did not exceed 16 kPa.

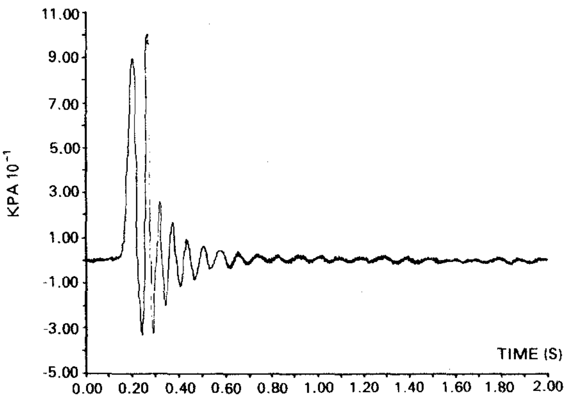

Fig. 15. Pressure trace: explosion in 1.2-m gallery. Toner dust, 1.5 kg, 2.0 s delay. Transducer 1.

The succession of peaks following the primary explosion peak correspond to the fundamental standing wave in the gallery.

Based on the polyethylene results, a constant ignition delay of 2 s was used to standardise the subsequent tests in the gallery.

Phenolic resin

The maximum pressure measured in this series of experiments (28 kPa) was obtained using 2.0 kg of injected dust. The maximum pressure recorded near the open end of the gallery was approximately 13 kPa.

Toner dust

The maximum pressure measured in these tests (90 kPa) was obtained using 1.5 kg of injected dust. The maximum pressure measured at the open end of the gallery was approximately 40 kPa.

Aspirin dust

The maximum explosion pressure recorded in these tests (43 kPa) was obtained using 2.0 kg of injected dust. The maximum pressure at the open end of the gallery did not exceed 15 kPa.

Summary of results

A summary of the measured maximum overpressures is presented in Table 9.

TABLE 9

Measured maximum overpressures (kPa)

Dust	Collector (normal operation)		Collector (injected dust)	In 1.2-m gallery
	rear vent	top vent	top vent	
Polyethylene	2	14	5.2	40
Phenolic resin	2	—	—	28
Toner	—	9	7.2	90
Aspirin	—	14	—	43

Discussion

The explosion pressures measured in the collector in these tests (2—14 kPa) are much lower than those measured in a similar filter during propane—air explosions [3] when pressures of 60 kPa were recorded. In a dust explosion, under real conditions, the local concentrations of dust and the total volume of the explosible dust cloud are not known. It is unlikely, however, that all the dust on the filter elements is dispersed and the volume of the dust cloud may be smaller than the volume of the filter. Although the explosion may be capable of dislodging dust from the filter bags and so, for a time, will be fed with fresh amounts of fuel, it is evident from the results obtained here that conditions necessary to obtain the highest explosion pressures are not produced.

In the 1.2-m gallery, however, the conditions of high turbulence and good dispersion are such as to produce high explosion pressures (40—90 kPa). It is important to note that good dispersion throughout the vessel and a high degree of turbulence are implicit in most methods for the estimation of overpressures during dust explosions. The results obtained here are compared with such a method in the next section.

Comparison of results with the K_{st} *nomograph predictions*

The most widely used venting method is the nomograph approach [1] recommend by VDI [4] and The National Fire Protection Association [5].

Figure 16 shows the predictions from the K_{st} nomographs published in VDI 3673 [4] for the case of a vent of area 0.99 m^2 opening at a gauge pressure P_{stat} = 0.1 bar and for three different volumes: the entire internal volume of the filter (6.73 m^3), the dusty side volume of the filter excluding the hopper (4.23 m^3), and the total volume of the dusty side including the hopper — and thus the maximum possible volume of the dust cloud prior to ignition (5.37 m^3). P_{stat} = 0.1 bar was the static bursting pressure of the vent cover material, but in some explosions the cover opened at much less than this pressure. This result suggests that vents can open at pressures less than the nominal P_{stat} if the pressure is applied rapidly. Points showing the maximum explosion pressures generated in the collector with top venting are shown on the graph. Because of the limited number of tests, it is unlikely that the worst case conditions were obtained for each dust, but in general, the K_{st} method provides a reasonable upper limit to the explosion pressures. In the case of polyethylene, for which most of the tests were done, there is excellent agreement between the highest maximum pressure experimental result and the prediction based on the total volume of the dusty side of the filter (5.37 m^3).

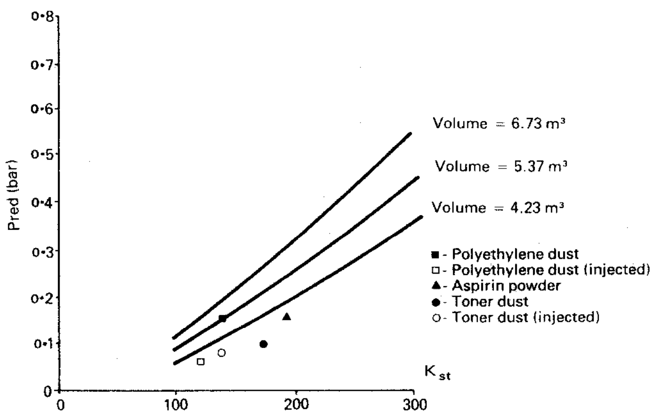

Fig. 16. Maximum experimental pressures measured in dust collector, compared to predictions from K_{st} nomographs.

The pressures generated in the back-vented polyethylene explosions were much lower than predicted, at most 2 kPa. For these explosions the ignition source was close to the vent and this is a favourable condition for keeping explosion pressures low since the burnt gases are discharged at an early stage of the explosion. The differences between the pressures in the back-vented explosions and those in the top-vented explosions emphasise the importance of obstacles between the ignition source and the vent. It is unlikely that a highly turbulent cloud is initially created when dust falls from the filter bags. However, the passage of the explosion between the grid of filter elements induces turbulence, the flame is accelerated and so higher pressures are generated. Furthermore, dust not previously dispersed from the filter bags may be dislodged by the explosion and provide the flame with fresh fuel.

When dust clouds injected into the collector were ignited, the explosion pressures were low, relative both to the results obtained in real working and to the K_{st} predictions. However, if the nominal concentration of injected dust is calculated by dividing the weight of dust injected by the volume of the dusty side only (5.37 m^3) then a K_{st} value applicable to these experiments can be obtained. Thus, the nominal concentration of injected polyethylene is 0.28 kg/m^3, and the K_{st} value at this concentration is 120 bar m s^{-1}. The nominal concentration of injected toner dust is 0.19 kg/m^3, and the K_{st} value at this concentration is 140 bar m s^{-1}.

The maximum pressures generated by explosions of injected polyethylene and toner dust are shown in Fig. 16 at the K_{st} values relevant to the nominal concentrations. Generally, the K_{st} nomograph predictions are a reasonably close prediction. The unexpectedly low experimental values may be the result of several factors: vent opening pressures below the nominal value of 0.1 bar gauge; ignition of the dust cloud at a non-optimum time for generation of the highest possible pressures; lack of dust on the clean filter bags which, in normal working, could feed into the explosion. It is also possible that some of the initial turbulence expected from the method of injection could be smoothed out prior to ignition in the narrow channels between the filter bags.

Maximum explosion pressure: 1.2-m gallery tests

In the 1.2-m steel gallery experiments, a well dispersed dust cloud was ignited at a delay time chosen to yield high explosion pressures. These conditions contrast with those pertaining to the experiments in the collector.

The K_{st} nomograph predictions do not strictly apply to these results since (i) the gallery was open-ended, therefore P_{stat} = 0 which lies outside the

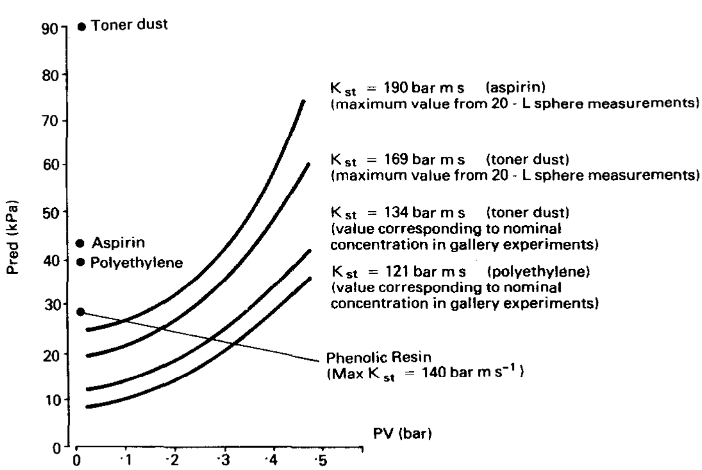

Fig. 17. Maximum explosion pressures measured in 1.2-m diameter gallery, compared to predictions from K_{st} nomographs.

range of the nomographs and (ii) the L/D ratio of 6.3 is outside the range for which the nomographs are applicable. Nevertheless it is of interest to note the degree of departure from agreement, and in Fig. 17, predictions from the K_{st} nomographs published in VDI 3673 [4] are shown for a series of K_{st} values along with the maximum explosion pressures generated in the gallery experiments.

Although the worst case conditions may not have been obtained, the experimental pressures always exceed the predictions. This underestimation of the explosion pressures is true regardless whether the K_{st} value corresponding to the nominal dust concentration in the gallery of the maximum K_{st} value for the dust is used to make the prediction.

Propane—air explosion

The pressures generated by a propane—air explosion in a collector similar to the one used in the present tests were about 60 kPa with top venting (0.99 m^2 vent area) and conditions simulating an St2 dust [3]. This pressure is in excess of the values predicted for an St2 dust by the nomograph method, as is demonstrated in Fig. 16.

The published value of K_G for propane—air is 75 bar m s^{-1} with low energy ignition and a quiescent mixture [1]. However, in the collector configured as for the present tests a rate of pressure rise equal to 110 bar s^{-1} was measured [3] in a propane—air explosion, corresponding to a K_G value of 193 bar m s^{-1}. This enhancement of the burning rate presumably occurred because of turbulence generated as the flame passed between the filter bags on its way to the vent. The rates of pressure rise in the present series of dust explosions in the collector are well below the values expected from the K_{st} values measured in the 20-l sphere as might be expected because of the different method of dust dispersion.

Although the worst conditions for the dust explosions may not have been obtained in the present tests it is unlikely that St1 and St2 dust explosions would generate pressures in the collector as great as those given by gas explosions.

Conclusions

These tests have shown that dust explosions in an industrial dust collector working under real-life conditions do not generate high explosion pressures when the ignition source is present inside the collector. If conditions are favourable, i.e. a vent close to an ignition source, then pressures do not exceed 2 kPa. When the explosion can generate turbulence before being vented, however, higher pressures (up to 14 kPa) can be obtained. Conditions for these increased explosion pressures are present in a collector if the flame passes between the racks of filter bags before reaching the vent.

The maximum explosion pressures generated in the collector in these tests are predicted reasonably well by the K_{st} nomographs. Because the number of tests was limited, there is no guarantee that the worst case conditions for each dust were obtained, but if the predictions are based on the largest volume of the collector that can be filled by a dust cloud prior to ignition, then they provide satisfactory upper estimates of the likely explosion pressures. A gas explosion in the collector does not satisfactorily simulate the effects of a dust explosion.

In practice ignition sources may occur outside the collector, and an explosion will then propagate into the collector along ducting. In these circumstances higher explosion pressures may well be generated than in the present series of tests.

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