EXPLOSION SUPPRESSION & AUTOMATIC EXPLOSION CONTROL

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History in the U.K., U.S.A., Europe & later work in Western Germany; Principles, the cube-law, time available for suppression, system test results; Hardware, description & operating experience; Suppressants, including use of powders.

INTRODUCTION

The development and manufacture of a method for automatically suppressing industrial explosions of the gaseous/air or dust/air type was undertaken by the Graviner Manufacturing Company in the 1950's with a small team headed by the author. The basic method was patented in 1948 by two scientists, Glendinning and MacLennan(1) at R.A.E., Farnborough, who had in mind the protection of aircraft fuel tanks against incendiary strikes. They realised that the early stages of pressure growth in vapour phase explosions was relatively slow. They reasoned that if the incipient explosion could be detected early enough, during the period when the explosion flame was still very small, it might be possible to extinguish it by using a small explosive charge to disperse an extinguishant into the space where the flame was growing, before the explosion pressure had risen to a dangerous value.

They successfully suppressed explosions in this way on a laboratory scale, employing a pressure switch, sensitive to rate of increase of pressure, to fire an electrically operated detonator which, by hydraulic shock, distributed an extinguishant from a container. As the system developed the containers - known as suppressors - took various forms which are described. Apart from the use of such a system for protecting aircraft fuel tanks, the original patent envisaged its use in mines as protection against methane and coal dust explosions, and for industrial applications where there was hazard of explosions of mixtures of oxygen (air) with vapours, sprays, mists or dusts. It

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is with the development of the system for use with industrial applications that this paper is concerned. However, it is of interest to note that it is only in recent years that the possibility of mining use has begun to be explored (2). The reasons for this are probably firstly that the industrial system has withstood the test of time, and secondly, increasing mechanisation at the coal face could more or less confine the system to the zone of ignition, so that hazard to personnel from fortuitous operation of the system is minimised.

HISTORY

Prior to the Glendinning, MacLennan experiments a patent in 1944 by Finch (3), directed particularly at metal dust explosion hazards in metal dust grinding plants, envisaged the use of a photo-electric, or fast response heat sensitive, explosion flame detector to initiate explosive means of isolating that part of a plant where an explosion originated from communicating parts. He also proposed separately, or in combination, explosive means of distributing a non-flame propagating dust or vapour cloud in advance of the explosion flame. His ideas therefore, seem to anticipate some of the techniques - isolation and advance inerting - which are now in use.

His system failed primarily because dust obscured the photo-cell - a difficulty which could probably have been overcome by persistent engineering development - and never came into practical use. However, it also relied on electronic amplification of the small photo-cell output by thermionic valves, before the advent of the reliable solid state amplifiers now available. The beauty of the Glendinning MacLennan patent was the inherent simplicity and reliability of the pressure switch and therefore the avoidance of any need for amplification of small signals from a transducer. A further important advantage of an explosion detector responding to pressure is that it does not depend on radiation, which can be obscured by the explosive medium, but senses pressure changes which travel at the speed of sound in the medium.

In air, the velocity of sound is approximately 1ft./millisecond (say 300mm/ms) so the location of the pressure switch in relation to the ignition source, although it must be considered, generally presents no problem. This delay in detection - known as "equalisation time" - between growth of pressure resulting from the expanding flame front and the sensing of the change, is an appreciable proportion of the total time available for suppression but normally allows more than sufficient time. If for any reason, such as in a long duct, equalisation time becomes unduly long using one detector, it can be reduced by two-thirds by employing two equally spaced ones, and so on.

Metal dust explosions are excluded from the foregoing because the flame temperature and rates of pressure rise are usually much greater and no extensive work has been done on the possibility of suppressing these. However, it is of interest to note that Brown & Williams (12) were successful using photoelectric detection of flame, in preventing the propagation of aluminium flake explosions in ducts by the explosive dispersal of stone dust ahead of the advancing flame, providing there was an explosion relief vent between the point of ignition and the stone dust cloud.

When the author commenced the engineering development, for the Graviner Manufacturing Company, of the explosion suppression system for industrial use in 1952, it was expected that most applications would be associated with gaseous/air mixture hazards, but in fact it turned out that the requirement was mostly for the protection of plants with dust explosion risks. It also quickly became apparent that the automatic control of explosions was not simply a matter of extinguishing the explosion flame in a particular part of a plant. For if the ignition occurred near an exit to a contiguous section flame could propagate into this and this would be more likely to happen in the same direction as the air flow than against it. Indeed, it is clear that the flame speed would be the sum of the normal flame speed and the air speed. In such circumstances it is therefore necessary to inert the adjacent part of the plant in advance of flame or burning material, or alternatively to isolate it, methods which have now become known, respectively, as "Advance Inerting" and "Isolation". Similar considerations apply to plants which are provided with explosion relief vents.

Practical application of the system commenced in this country about 1953. Between July 1954 and April 1961 in the U.K. somewhere between 100 and 110 successful operations of systems in 20 separate installations are recorded. Some 900 installations, mostly on plants subject to dust explosion, were in use in 1973 in the U.K. The author introduced it to the U.S.A. in 1958 (13) when it had been taken up (then under licence from the Graviner Manufacturing Company) by Fenwal Incorporated. The pattern of development in the U.S.A. has been similar except that the number of installations is greater and their size tends to be larger. The approximate world-wide distribution of automatic control systems in 1979 is tabulated below :-

U.S.A.	2450
Canada	50
Europe	30
Asia	17
U.K.	1080
Total	3627

In 1973 there was a total of 92 actuations of systems serviced by the U.S.A. interests. Of these, 60% were confirmed suppressions, i.e. explosion damage was prevented, 16% were due to process upsets such as blockages, and 24% were caused by process personnel errors. The number of actuations is now about 150 p.a. and the percentage of confirmed suppressions etc. is about the same.

The types of industry employing systems are :-

	%
Wood(in particular wood flour)	29
Plastics	20
Food	16
Pharmaceuticals	9
Petroleum	8
Paint (powdered)	6
Solid waste	5
Others	7

In the U.K. the history of successful use goes back 26 years, in the U.S.A. 21 years and the suppressants used are mainly halons. These systems have not been employed except to a very limited extent in Germany largely because neither the U.K. nor U.S.A. interests had any effective representation in that country. More recently Bartknecht (19) working with Total equipment and also with some modified Graviner equipment, found it possible to suppress explosions using powder extinguishants such as ammonium phosphate but with the penalty, for reasons discussed later, that the suppressed explosion pressure is higher being about 0.6/1 bar (10/15 lbs/sq.in) as compared with 0.13/0.2 bar (2/3 lbs/sq.in) or less with halons. At the time of writing it is believed that between 100 and 200 Total powder systems have been installed in Germany.

PRINCIPLES

The feasibility of explosion suppression arises from the fact that the pressure/time relationship in gaseous/air mixtures explosions follow a cube law of the form :

$$p = K. \frac{Sr^3t^3P}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where
p = pressure at any instant
Sr = radial flame speed
P = maximum pressure reached in a contained explosion
V = volume in which the explosion is occurring

This cube law relationship is valid for initial pressures different from atmospheric (provided Sr is considered constant) up to rather more than half the maximum explosion pressure in the cylindrical and rectangular types of vessel normally met with in industrial practice, and for volumes where the length/diameter ratio approaches unity. In vessels of large L/D ratio the relationship will depart from the cube law when the spherically expanding explosion flame reaches the vessel wall and since, thereafter, the flame can only travel in directions not limited by the wall, the rate of flame and pressure increase will be slowed down, at least initially (4,5).

It would be expected that the pressure and flame growth time would follow a cube law since a point source of ignition expands spherically if undisturbed, and as the radial flame speed is constant, at least in the early stages of the explosion the volume which the sphere of burnt gas occupies at any instant will be proportional to the cube of the radius. In suppressing an explosion one is, in any case, only concerned with the size of the flame and the corresponding pressure during the very early stages of the explosion when the pressure is less than say, 0.14/0.2bar (2 or 3 lbs/sq.in).

From Equation (1) it follows that :-

(a) In given volume $p = k\,t^3$ ....(2)

(b) Since the maximum explosion pressure P is practically independent of volume the time taken to reach a given pressure is :

$$t = kV^{\frac{1}{3}} \quad \text{..........................(3)}$$

(c) Knowing the time required to reach a certain pressure in a volume V the time tx required to reach the same pressure in a volume Vx is :

$$tx = \frac{Vx^{\frac{1}{3}}}{V^{\frac{1}{3}}} \,.\, t \quad \text{......................(4)}$$

(d) In a given volume :

$$p = kSr^3 \quad \text{..........................(5)}$$

The foregoing approximations apply to explosions taking place under conditions of non-turbulent burning. Turbulence will increase the rate of combustion and therefore the rate of pressure rise, considerably (4,7,8,9). Multiple sources of ignition also increase the rate of pressure rise (6).

These expressions are useful since they enable, with care, the parameters of an explosion of one combustible to be used to approximate the behaviour of another of different flame speed.

Figure 1 is a family of curves showing how the time taken to reach a given pressure varies with the volume in which the explosion is occurring and can be used to represent hexane and related hydrocarbons. The curve was due to Glendinning up to volumes of 5.7 cu.m (200cu.ft) and has been verified by other workers. The author in some experimental suppressed explosions was able to verify the extension of this to about 28 cu.m(1000 cu.ft) for pressures up to about 0.14bar(2lbs/sq.in). The later Swedish tests (6) showed that these relations could be extended to 198cu.m(7000cu.ft) and Hillerbrand(6) suggested extension to 1400cu.m (50,000cu.ft) or so.

Reference to Figure 1 enables approximations to be made of the time available for an automatic explosion suppression system to operate in a hexane or similar explosion. For example in a 0.028cu.m(1cu.ft) vessel about 25 milliseconds is available, but in 2.8cu.m(100cu.ft) there is about 102 milliseconds before this pressure is reached.

Thus, following from equation (4), the larger the volume in which the explosion is occurring, the longer is the time available for suppression. This, of course, is very convenient because the flame is larger in the larger volume and requires more extinguishant to put it out. Suppressors for large volumes can therefore have a longer operating time. It must be borne in mind that the whereabouts of the ignition source is rarely known and so the whole of the volume must be filled with suppressant in this time, consequently more suppressant is required than would be necessary if the position occupied by the flame was known.

The time required for a suppression system to operate is the sum of the following elements :-

Time required for the explosion pressure to reach the pressure at which the detector operates	td
Time required for the growing pressure changes to reach the explosion detector - Equalisation time	te
Time required to fire the detonator which initiates the distribution of the suppressant	tf
Time required to distribute the suppressant throughout the whole of the volume	ts
Total time	td + te + tf + ts

td is determined by the volume and consideration of the normal plant operating pressure. It is necessary to strike a balance between the lowest permissible operating pressure for the detector and a reasonable margin above the maximum plant operating pressure. The latter must usually be the maximum pressure likely to be reached under a fault condition such as a blockage. For the following example, the plant is considered to be 0.28cu.m (10cu.ft), the plant operating pressure is taken as atmospheric, and a detector setting of 0.007bar (0.1lbs/sq.in) is employed. From Figure 1, the time taken to reach this pressure in a volume of 2.83cu.m (100cu.ft) is about 45 milliseconds.

te depends on the geometry. In the case of a 3.05m cube (10ft cube) a detector mounted in the centre of one side would, in the least favourable case, give an eqalisation time determined by the distance to an opposite corner, say 3.7m(12ft) of about 12 milliseconds.

tf is a characteristic of the electrically fired detonator and the current used to initiate it, and is kept below 1 millisecond.

Thus, td + te + tf is 45 + 12 + 1 = 58 milliseconds by which time, from Figure 1, the pressure would have risen to about 0.017bar (0.25lbs/sq.in). If the explosion pressure is not to exceed 0.17bar (2.5lbs/sq.in), by when the lapsed time will be about 102 milliseconds, there is 102-58 = 44 milliseconds left in which to distribute the suppressant.

The whole of a volume of this size could be inerted within 10 milliseconds if need be but as there is plenty of time available, economic considerations would usually dictate the use of a slower suppressor.

Figure 2 shows the sequence of events during the suppression of a most explosive hexane/air mixture in a 4.55cu.m (1000 gallons) vessel of small L/D ratio.

An important function of any automatic explosion control system is that of initiating automatic plant shut-down when explosion is detected. Conversely, the system is usually interlocked in such a way that the plant cannot be started unless the system is in operation.

Because dust explosions are more difficult to reproduce consistently, most of the early development of the system was done using gaseous/air mixtures. The similarities and difference between gaseous and dust explosions were discussed by the author in a Review of the Literature on Gaseous and Dust Explosion Venting (10) in 1965 wherein, for the first time, it was pointed out that there was evidence and good reason to suppose that dust explosions also followed the cube law and suggested some experiments to demonstrate this. Since then work at the U.S. Bureau of Mines and also by Bartknecht (19) in Germany has demonstrated the validity of the cube law for dust explosions.

Following the suggestion in (10) Burgoyne (11) had measurements made of rates of pressure rise in the Hartmann apparatus for a typical range of gases with the object of applying gas explosion relief formulae to dusts. These results, together with those for some typical dusts (10) are tabulated below :

GAS	dp/dt lbs/sq.in/sec
Methane	2625
Propane	3600
Ethylene	7770
Hydrogen	18500

DUST	dp/dt lbs/sq.in/sec
P.V.C.	200
Coffee, instant, spray dried	500
Soya flour	1500
Milk, skimmed	2300
Coal, Pittsburgh	2300
Nylon	3600
Sugar	5000
Polystyrene	5000
Cellulose acetate	6500
Wood flour	7500
Cornstarch	9500

In the case of the gases the mixture at the commencement of each explosion was quiescent but for the dusts a considerable degree of turbulence is inherently involved in the Hartmann method of test. No work has yet been done to determine the degree of turbulence present in industrial plants having dust explosion risks but it is obvious that there are differences which range in a scale of increasing turbulence from that in a hopper or silo being filled by gravity to the conditions in grinders and pulverisers. Until work has been done on this the severity (dp/dt) of a dust explosion must remain a matter of judgement. My own opinion was that Hartmann test results tend to exaggerate the severity except possibly for grinders and pulverisers. For some time I have used these and similar Hartmann gas/dust comparisons to approximate dust flame speeds both for dust explosion venting problems as well as to modify Figure 1 to cope with dust explosion suppression questions. However, Bartknecht's work and more recently that of Moore (20) must now be taken into consideration as well. It is hoped that Moore's paper at this symposium will help to clarify this situation.

In (10) it was also suggested that work should be done to discover the likely degree of turbulence present during the normal operation of dust plants so that this could be related to Hartmann test results. This has not yet been done but is likely to be forced upon us shortly because of the German dust explosion test philosophy.

I would like to make it clear at this point that the turbulence being referred to is that present within the plant at the commencement of the explosion, and due entirely to the operating conditions within the plant. To what levels the turbulence can rise due to obstructions within the plant and other factors in later stages of a freely developing explosion is entirely another matter. In the design of a suppression system it is only the rate of increase of pressure in the early stages of explosion which must be considered.

SUPPRESSANTS

The agent normally used in U.K. and U.S.A. practice is C.B. (Chlorobromomethane, CH_2BrCl) because it is the most effective, on a vapour and liquid volume basis, of the halons available. The table below shows the concentrations of various halons required to render heptane/air most explosive mixtures non-flammable in descending order of effectiveness :

AGENT	HALON NUMBER	CONCENTRATION FOR NON-FLAMMABILITY (17)		
		% Volume of Agent Vapour	% Volume Liquid Agent	ccs/cu.ft Liquid Agent
Chlorobromomethane (C.B.), CH_2BrCl	1011	7.6	0.022	6.2
Methyl Bromide (M.B.), CH_3Br	1001	9.7	0.024	6.9
Bromotrifluoromethane (B.T.M.), $CBrF_3$	1301	6.1	0.026	7.3
Bromochlorodifluoromethane (B.C.F.) $CBrClF_2$	1211	9.3	0.037	10.6
Carbon tetrachloride (C.T.C.), CCl_4	104	11.5	0.049	14

Originally the practice was to use a C.B. concentration of 2.2 ccs/litre (0.22% of volume to be suppressed) which was about

10 times the amount theoretically required to inhibit combustion. With increasing confidence and depending on test results somewhat smaller concentrations may be used.

Whilst C.B. is the most effective halon suppressant others may be preferred for particular problems. For example, C.B. has been very effective in suppressing explosions in styrene grinding operations but forms a mastic mess within the plant which occupies time in removal. A more volatile suppressant such as halon 1301 would probably avoid this.

It is desirable to test a suppressant with the particular explosive mixture if there is no previous experience with the combination.

Water may not be a very effective suppressant for gaseous/air mixtures but is effective in the case of many dusts. It is also useful for drenching open loading chutes where there is danger of flame escape.

For advance inerting other agents such as CO_2 may be desirable where a period of continuous inerting over several minutes is required.

In Germany Bartknecht has done much work using inert powders such as ammonium phosphate as a suppressant. The German philosophy on explosion protection is different to that of the U.K. and U.S.A. where most dust plants are only capable of withstanding 0.2/0.28bar (3 or 4 lbs/sq.in) with the consequence that the protection system (suppression or venting) is tailored to keep the explosion pressure below this. When powder is used as a suppressant it is not usually possible to keep the suppressed explosion pressure much below 1 bar (say 15 lbs/sq.in) and the German rule that new plants must be capable of withstanding 1 bar appears to be a consequence.

The reason for this disadvantage is the fact that it has not proved possible to distribute powder throughout the volume concerned as rapidly as is possible with the liquid suppressants. Powders are, however, very effective suppressants when in position because of their immense capacity to absorb heat due to the very large particle surface area. This coupled with the fact that they will not burn means that however late they may be distributed during the course of an explosion, they will make some contribution to reducing the explosion pressure if maximum pressure has not been reached. Thus, the use of powder as a supplement to venting in difficult venting cases is indicated.

The halon suppressants will burn if the temperature is high enough and they are within their own flammable limits (18). Of course when used for explosion suppression the amount of halon employed is normally well above its own upper flammability limit.

HARDWARE

Under this heading is described the components which are available for automatic explosion control. Routine maintenance is essential for a high level of confidence. The important checks are mentioned.

Explosion Detector

The British (Graviner) design embodies a stainless steel pressure sensitive diaphragm carrying an electrical contact which makes with an adjustable contact at the predetermined pressure. A variation of this design is a pressure switch responding to rate of increase of pressure which may be an advantage in applications subject to large excursions in normal operating pressure.

The contacts are of platinum to minimise the possibility of corrosion. One has a very much smaller surface radius than the other so as to break through any surface film that might form due to condensation and evaporation. To make doubly certain of breaking through any such film, the system voltage is 200. The assembly is temperature compensated, by suitable choice and dimensions of materials, so that temperature variations between 0°C and 250°C do not sensibly affect the operating pressure. The contact space can normally only breathe through the electrical conduit, but if an M.I.C.C. system of wiring is used a filter to atmosphere is incorporated to ensure that the side of the diaphragm not exposed to the plant pressure remains at atmospheric pressure. In appropriate circumstances a flame trap may be incorporated in the filter.

To minimise fortuitous operation of the detector due to vibrations British practice is to use two detectors with their diaphragms mounted in planes at right angles and connected electrically in series. The explosion pressure will then operate both but only one contact is likely to be closed by chance. The U.S. practice sometimes is to support the detector rigidly from the building structure and connect it to the plant via a short length of flexible hose.

The operating pressure should be checked at regular intervals.

Photo-electric flame detectors have been used where pressure conditions have made the pressure switch unsuitable and can be used where speed of operation over-rides other considerations. Because of attenuation of the radiation by the explosive medium they would not normally be suitable for dust explosion risks except where the detector has only to look across a short distance.

The Electrical Power Unit

This provides the electrical energy for firing the electrically operated detonators used for distributing, or initiating the distribution, of the suppressant, for closing valves, or in some cases for opening bursting discs, or water deluge valves. It incorporates a number of safeguards.

(a) The electrical system is interlocked so that the plant is automatically shut down when explosion is detected and cannot be started until the protection system is armed.

(b) All detonators are connected electrically in series and are continuously monitored by a small current of about 2 milliamps which holds in a relay. Should an open-circuit occur this relay falls out, gives warning of this condition, and normally is arranged to shut down the plant automatically.

(c) The electrical energy for firing the detonators is stored in two large capacitors either of which provides more than sufficient.

(d) A standby dry battery automatically takes over in the event of mains failure.

Batteries should be checked at intervals.

Suppressors

Three types are available, hemispherical, cylindrical, and high rate discharge. The hemispherical and cylindrical suppressors give the fastest rates of discharge and are used for comparatively small volumes. They employ the energy available from the explosion of detonators directly for dispersion of the suppressant. The high rate discharge suppressor uses a detonator to open a large container from which the suppressant is then ejected under a pressure of 21 bar (300lbs/sq.in) usually via an elbow and spreader. Hemispherical and cylindrical suppressors, as their shape and name suggests, produce hemispherical and cylindrical spray patterns. They are normally mounted within the plant to be protected and have a temperature limitation, largely dictated by the detonator, of about 60°C. The high rate discharge bottle (HRD) as it is called, is normally mounted on the outside of the plant and can therefore cope with higher plant temperatures. Comparative performance of suppressors is given below :

SUPPRESSOR SIZE : litres	AVERAGE DISTRIBUTION VELOCITY: m/s	APPROXIMATE SUPPRESSED VOLUME: cu.m	EFFECTIVE DISTRIBUTION TIME (tf + ts) milliseconds
Hemispherical Suppressors			
0.5	60	0.23	8
5	30	2.3	30
High Rate Discharge Bottles			
3	20	1.4	110
10		4.6	200
35		16	600

Suppressors should be examined and weighed at intervals to check for damage or leakage.

Armour Plate Glass Bursting Discs

For plant operating pressures much above atmospheric or involving considerable pressure fluctuation, the design of conventional explosion pressure operated relief vents becomes difficult. The use of armour plate glass enables a relief area of virtually any size to be obtained. The glass is broken in the familiar windscreen manner, by means of an electrically operated detonator triggered by an explosion detector set at the desired relief pressure. One does not employ this type of vent light-heartedly, without consideration of the missile problem.

High Speed Isolation Valves

These are used both to stop the propagation of dust explosions in ducts and to preserve an inert atmosphere by preventing suppressant from being swept out of a system e.g. when fans are running down.

They have been made in plug; flap and butterfly form and are closed by means of a powerful spring the energy from which is released by shattering a tension member with a detonator. A typical 16" plug valve can be closed in this way in less than 80 milliseconds. Tests of the effectiveness of these valves in stopping the propagation of dust explosions in ducts have been carried out by H.M. Factory Inspectorate (14). Usually the valve is associated with the simultaneous operation of a suppressor to extinguish any flame which might get through while the valve is closing, or bouncing. In this way the combination can achieve isolation within about 10 milliseconds.

TYPICAL APPLICATIONS

Under this heading are described some typical applications of automatic explosion control systems.

Grinding and Dust Collecting Plant

Figure 3 shows a hypothetical grinding and dust collecting plant in which most of the system components available have been included to illustrate how they can be used. The grinder is suppressed using one or more hemispherical suppressors (S) and the cyclone with two HRDs. The cyclone explosion detectors (D) are usually mounted on the inlet scroll and those for the grinder may be located below the flails or shredder in a position where material cannot directly impinge on them. Both detector pairs would be connected in parallel so whichever was triggered first by the explosion would simultaneously initiate the following :

1) Suppressor discharge in the grinder and cyclone.

2) Plant shut-down, including the fan.

3) Closes the high speed isolation valve (V) at the outlet of the bag filter to prevent suppressant being swept from the system.

4) Inerts the bag filter in advance of flame from the cyclone by injecting suppressant at a fast rate from suppressors located at the inlet and elsewhere.

5) Injects suppressant (¾HRD), at a slow rate, behind rotary gate valves to extinguish any smouldering material which might otherwise be carried round into the conveyor system, or possibly the feed hopper.

The filter is vented as it is not normally practical to suppress bag filters because of the large spaces in shadow of the bags. One type of filter (the Dalmatic) can be suppressed because the bags comprise parallel rows of envelopes and the spaces between can be reached by the radial discharge from cylindrical suppressors. Tests (15) carried out by I.C.I. in 1964 using pentane/air mixtures instead of dust, showed that the suppressed explosion pressure did not exceed 0.21bar(3lbs/sq.in) When the tests were repeated using hemispherical suppressors the suppressed explosion pressure rose to 0.7bar(10lbs/sq.in).

It will be appreciated that whilst flame will usually travel in the direction of the normal air flow reversal of flow can take place when the explosion pressure exceeds the pressure causing normal flow. Thus one must not assume that no flame will appear at the grinder feed inlet and a suppressor - possibly containing water - may be desirable at such inlets, and other similar situations, to protect operators.

Bucket Elevator and Conveyor System

In the installation shown at Figure 4 the elevator itself is protected by explosion relief vents, but to prevent flame propagating along the associated conveyors they are inerted by HRD bottles. Hemispherical suppressors at the top and bottom of the elevator provide rapid inerting of these spaces in the interval before the HRD bottles become fully effective. This is *an example of the use of 3 sets of explosion detectors to reduce* equalisation time because of the height of the elevator. Elevators can be suppressed providing arrangements are made to ensure that the buckets cannot shadow the suppressant.

Sulphur Grinding

Figure 5 shows a type of grinder operating on compressed air known as a Microniser, where the product - sulphur - is collected in a large bag filter. The grinder is strong enough to withstand the explosion pressure and the system is designed to protect the bag filter which is advance inerted with an HRD bottle. As the inerting of the bags is relatively slow, hemispherical suppressors lay down a quick screen in the grinder and duct to minimise the possibility of flame reaching the bags before inerting is complete.

Pulverised Fuel

In the application shown in Figure 6 the pulverised fuel bins are protected from bursting by means of conventional pressure operated bursting discs and the function of the explosion detector is to operate banks of HRD bottles to extinguish any residual fire. Temperature detectors (T) are connected in parallel with the explosion detectors to operate the HRD bottles in the event of a fire which does not lead to an explosion. In some cases the explosion detectors may take the form of a vent operated switch.

Flour Bins

The flour bin in Figure 7 is suppressed by means of a 5000 cc hemispherical suppressor. Flame is prevented from entering the Redler conveyor by a suppressor mounted in the discharge chute.

SOME TEST RESULTS

Dalmatic Filter Suppression

Figure 8 shows the range of the results of three I.C.I. tests (15) of the suppression of pentane explosions in a Dalmatic filter using cylindrical suppressors. Two tests involved ignition in the centre of the filter bags and one at the bottom of the cabinet. The latter gave the highest pressure.

Low Strength Building Suppression

Fenwal undertook a study in 1972 (16) to show the feasibility of suppressing explosion in facilities handling natural gas (methane). A room was constructed of plywood sheets on a metal frame with joints stopped with tape. There was a standard door at one end and blow-out panels of hardboard at the other.Ultra violet light detectors operated 3-35litre HRD bottles. The volume was about 85cu.m (3000cu.ft) which is the largest which has so far been suppressed. Previously the largest volume in which suppression had been demonstrated was in the 28cu.m (1000cu.ft) tests by the Swedish Air Board of the Graviner system in 1953 using a pressure detector. Figure 9 shows the pressure records of three suppressions. The maximum pressure reached was 5.6mmHg (3" of water).

Swedish Tests

The pressure record shown at Figure 10 of one of the rehearsals for the Swedish Air Board Test in 28cu.m(1000cu.ft). Note the output from the photo-cell showed that flame was extinguished.

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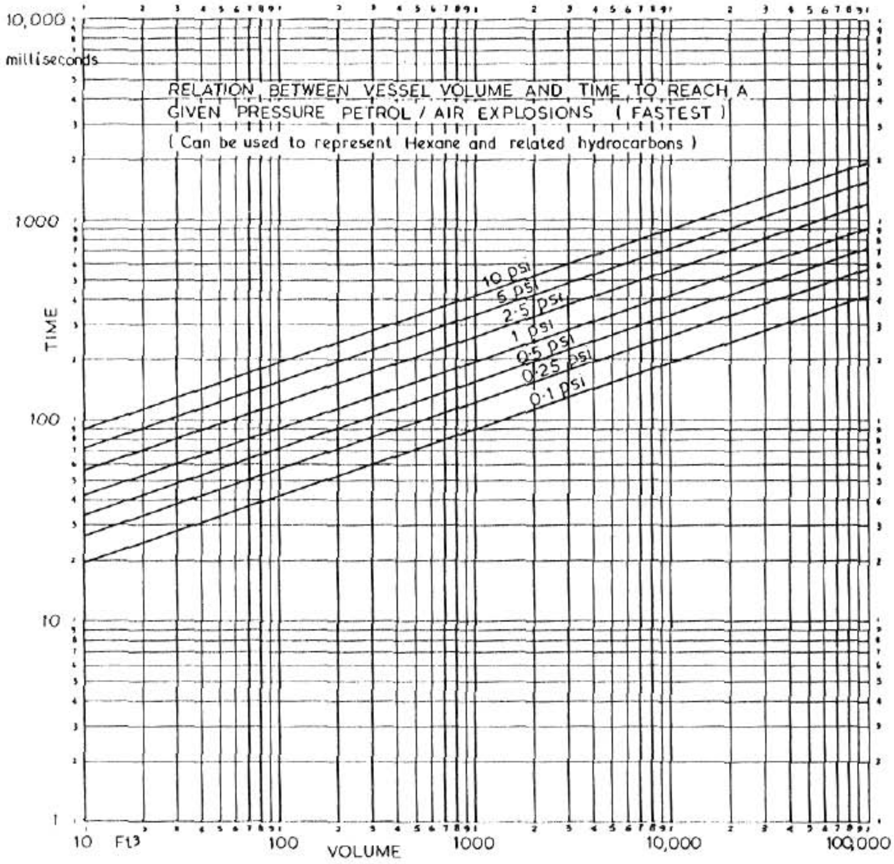

RELATION BETWEEN VESSEL VOLUME AND TIME TO REACH A GIVEN PRESSURE PETROL / AIR EXPLOSIONS (FASTEST)
(Can be used to represent Hexane and related hydrocarbons)
10 psi
5 psi
2·5 psi
1 psi
0·5 psi
0·25 psi
0·1 psi
10,000
milliseconds
1000
100
10
1
TIME
10
Ft3
100
1000
10,000
100,000
VOLUME

Fig.1

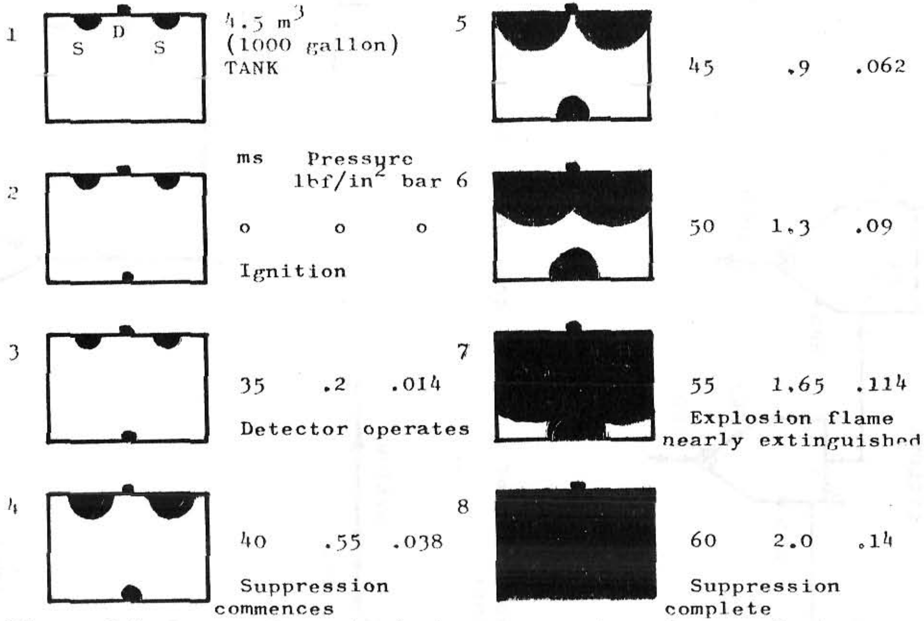


Figure 2 Sequence of events during suppression of an explosion

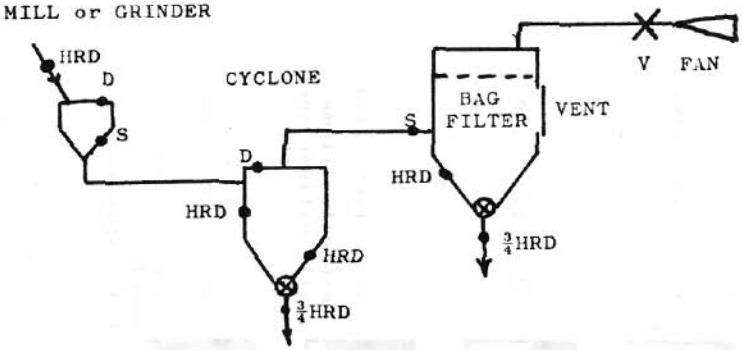
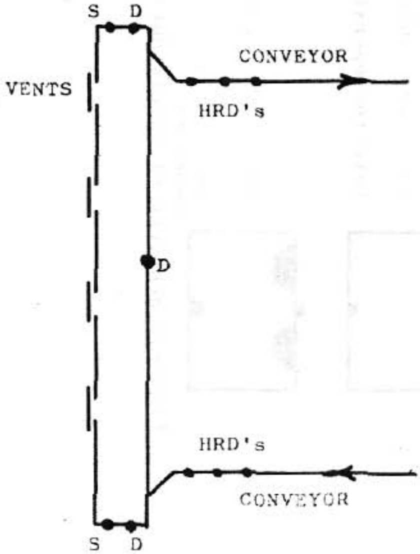


Figure 3 Protection of a typical grinding & dust collection plant



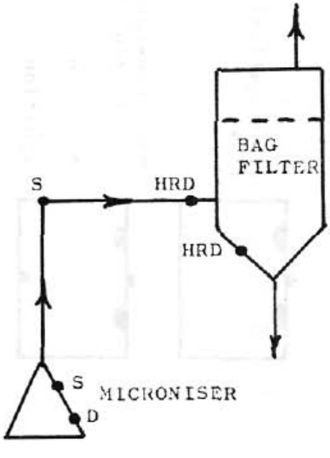


Figure 4 Protection of bucket elevator & conveyor system

Figure 5 Protection of a sulphur grinding plant

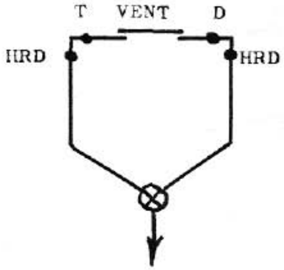


Figure 6 Pulverised fuel bin protection

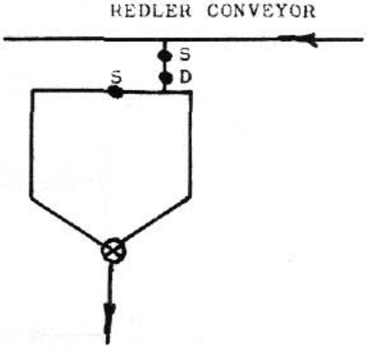


Figure 7 Flour bin suppression

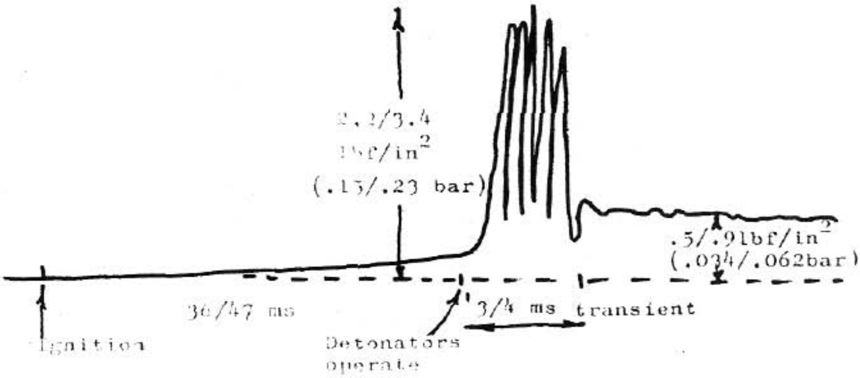


Figure 8 Suppression of [illegible] explosions in [illegible] bag filter

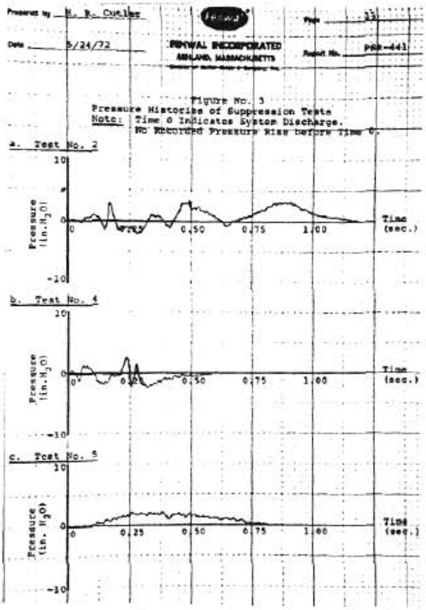


Figure 9 Pressures reached in large volume suppression tests

CONVERSION FACTORS

Unit	X	=
ft^3	0.0283168	m^3
m^3	35.3147	ft^3
lbf/in^2	0.0689476	bar
bar	14.5038	lbf/in^2
lbf/in^2	6894.76	Pa
Pa	10^{-5}	bar
bar	10^5	Pa
Pa	1.45038×10^{-4}	lbf/in^2

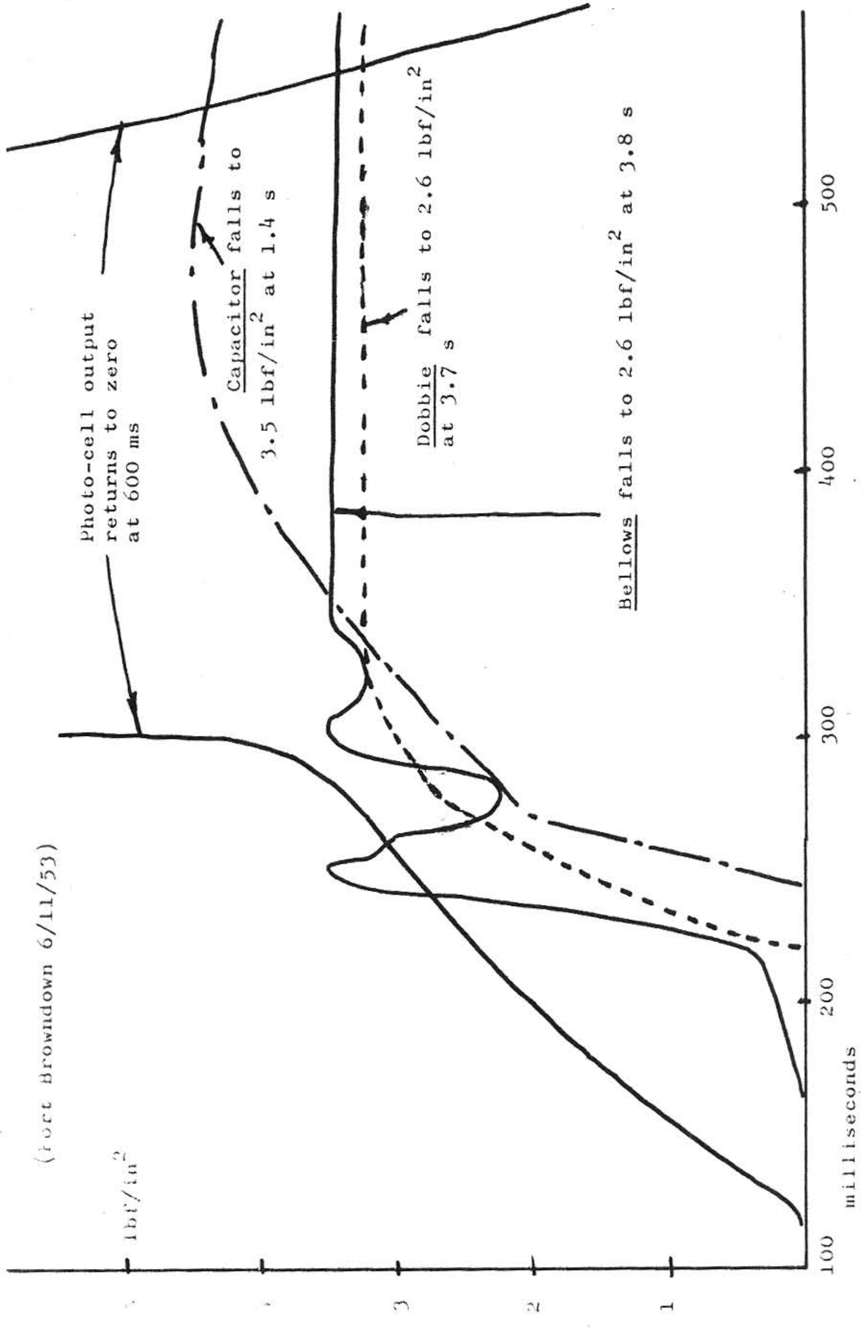


Figure 10 Suppression of most explosive pentane/air mixture in $28m^3$ (1000 ft^3)