PRESSURE PILING AND OTHER ISSUES AFFECTING FLAMEPROOF ENCLOSURES

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SUMMARY

This paper discusses the generation of overpressures in flameproof enclosures when subjected to flammable gas explosions. The failure of a flameproof enclosure which occurred recently in the United States is described. In the investigation it was concluded that the flameproof enclosure failed because of pressure piling and pressure wave superposition during a methane explosion. An occurrence of pressure piling in a flameproof motor which was being type tested by SIMTARS is also described. The mechanisms of overpressure generation during gas explosions in enclosures and the treatment of pressure piling in AS2380.2-1991 are examined.

A CASE STUDY FROM AMERICA

On January 16, 1995 an explosion occurred in the main longwall controller enclosure at North River No. 1 Mine in Berry, Alabama. The following information is from a report by the Approval and Certification Center of the Mine Safety and Health Administration (MHA)[1].

Description of the Incident

The explosion occurred in a five bay design enclosure with dimensions approximately 4500mm long x 900mm high x 650 mm deep. The interior of the enclosure was constructed as a single chamber, with components arranged as

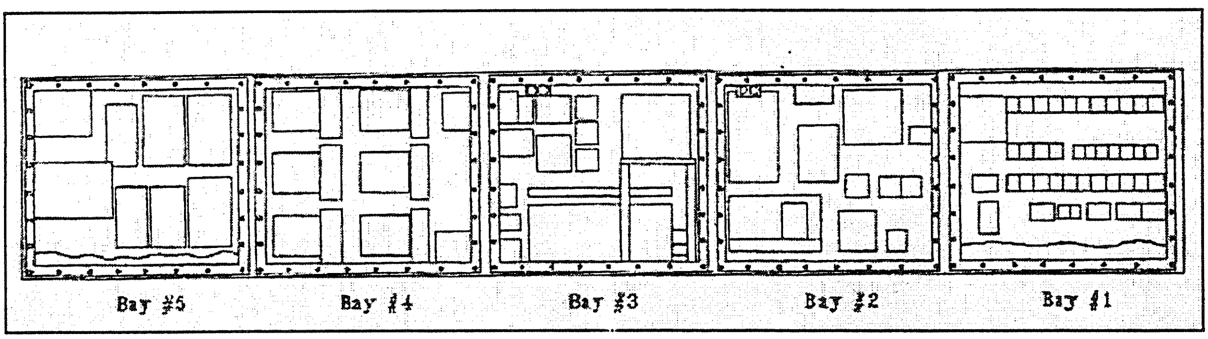

Figure 1 Layout of the flameproof enclosure which failed during an explosion at North River No. 1 mine

illustrated in Figure 1. Most damage occurred in the first compartment (Bay 1)from the right hand side. The damage included dislodgement and breakage of many components such as relays and circuit boards. The cases of several components were distorted and there was evidence of heating in each bay of the enclosure, but most severely in Bay 1.

In Bay 1, an aluminium cover plate of 3/4" 6016 aluminium alloy was permanently deformed 29/32" in the front near a polycarbonate lens. The back steel wrapper plate was deformed about 1/2". Mechanical tests suggested that the damage to the wrapper plate was consistent with a pressure rise of 200psig (about 1400kPa).

A polycarbonate window lens in Bay 1 used to view electrical meters fractured as a result of the explosion. Testing showed it to have failed as a result of overload bending. The steel frame surrounding the window was plastically deformed It was estimated that the force required to break the polycarbonate window was 653 pounds force.

The door of Bay 1 was also bowed by the explosion, to the extent that it no longer satisfied the dimensional requirements of the US standards for explosion-proof equipment.

Potential Fuel Sources Considered

Figure 2 Photograph of fractured polycarbonate window

There was no evidence that high power arcing had occurred in the enclosure, and so it was deduced that the explosion was caused by a gas ignition.
Potential fuel sources considered for a gas explosion were:

- volatisation of insulation or plastic materials
- gasification of lubricants used around push button switches
- coal dust
- hydrogen produced from either an electrolytic reaction or from battery gassing
- methane

It was considered that there was insufficient charring on equipment to have liberated sufficient gases to cause an explosion and there was no residual smell from plastic material which is generally associated with volatisation. Similarly the quantities of gas which could have been produced from the lubricant were too small to have caused an explosive atmosphere. For hydrogen to be produced by an electrolytic reaction requires water to be present, and there was no evidence of wetness. A 7.0 ampere-hour gelled-electrolyte lead acid battery was used for a battery back up . Overcurrent protection was provided to protect the battery against overcharging. Overcharging might cause excessive amounts of hydrogen to be liberated, but no evidence could be found that the battery had been overcharged. Tests were conducted to determine the rate at which hydrogen was liberated as a function of charging voltage and temperature, and the gas liberation was also calculated theoretically. Both these methods showed that it would have been extremely unlikely for a hydrogen gas explosion to have taken place in the enclosure.

By a process of elimination it was concluded that the most likely source of ignition was methane gas.

Potential Ignition Sources Considered

There were a number of potential ignition sources within the flameproof enclosure. The most likely source was considered to be the auxiliary contacts of a vacuum contactor. Several of the vacuum contactors from the enclosure were tested in an explosion gallery in methane/air mixtures of various concentrations. The contacts were easily able to ignite methane in the concentration range 6.5% to 10.5% . At the time of the explosion the longwall was being started in automatic mode, so ignition by switching of auxiliary contacts is quite feasible.

Conclusions drawn

It was concluded that the most likely scenario involved the initiation of a methane explosion in Bay 4 or 5, which propagated down the enclosure. In Bay 3 restrictions caused by large lighting and constant voltage transformers resulted in a reduction in cross-sectional area of about 72%. As the flame front passed through the restriction it formed a high pressure gradient, and this impulse was increased by a factor of two as it was reflected in Bay 1.

PRESSURE PILING

In the case study described, pressure piling and reflection of pressure waves caused an overpressure to be experienced in Bay 1 of the enclosure, which resulted in severe damage to the enclosure.
Australian Standard AS 2380.2-1991[3] defines pressure piling as "a condition resulting from ignition of pre-compressed gases in compartments or sub-divisions other than those in which ignition was initiated". It also states that "where an enclosure comprises two or more communicating compartments or is subdivided by the disposition of the internal parts of equipment, pressure piling may occur. This generally results in an abnormally rapid rise of pressure and may lead to a higher maximum pressure than would otherwise be expected. The shape of the inside of the enclosure shall be such that pressure piling is precluded, as far as practicable. If it is impracticable to avoid pressure piling the mechanical strength of the enclosure shall be increased to allow for it." Pressure piling is also considered in the determination of the explosion (reference) pressure, in the placement of transducers to detect the maximum pressure (ie the pressure measured in some locations is higher than in others.). Provision is also made

in the standard to use a higher factor of safety gas for Group IIA gases, in cases where a testing officer considers that pressure piling may occur.

In testing for strength and flame containment requirements of flameproof equipment, enclosures are normally fitted with blocks which approximate the shape and location of equipment as it will be placed in the enclosure. It is quite important that this be done as accurately as possible, especially when an enclosure has little free volume. Even cables can form obstacles which affect the gas flows consequently also pressure rises in enclosures.

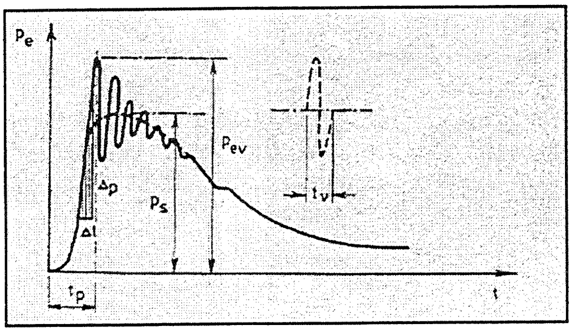

Figure 3 Typical waveform showing explosion pressure with oscillation from Marinovic [4]

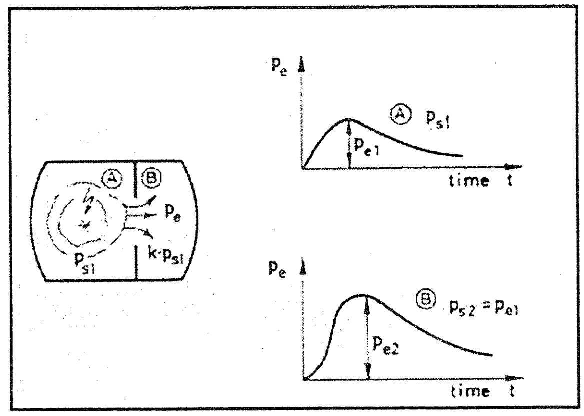

Figure 4 Typical waveform showing pressure piling during explosion pressure rise, from Marinovic [4].

Marinovic [4] discusses two types of overpressure generated in gas explosions. The first is an oscillatory pressure waveform that is superimposed on the envelope of the pressure rise. This is attributed to pressure wave reflections, and is more commonly found in irregularly shaped enclosures. The oscillations introduce dynamic stresses on an enclosure which can increase the combined stress on the enclosure by up to 50% in severe cases [4]. A typical pressure waveform is illustrated in Figure 3. Marinovic also describes the overpressures caused by pressure piling. The density of the gas in an enclosure affects the amount of energy which can be released into that part of the enclosure, which is directly related to the pressure rise generated when an ignition occurs. Hence, if a pressure wave causes unburnt gas to be compressed ahead of the wavefront, then when the pre-compressed gas ignites, it will generate an overpressure. A typical waveform of pressure piling also from Marinovic's book is shown in Figure 4.

In a study carried out by Conn [5] an elementary mathematical model was developed based on thermodynamic principles. The report acknowledges that pressure piling as high as 300 psi (2067 kPa) can be achieved for a methane/air explosion under laboratory test conditions. In one laboratory experiment conducted at MSHA, an 18 foot long 20 x 36 inch enclosure was badly distorted in an explosion test with a peak test pressure of 125 psig (862 kPa) recorded whereas in a previous test the enclosure had tested satisfactory with a peak pressure of 118 psig (814 kPa). The failure was attributed to either pressure piling or combustion instability due to the flame front.

Working guidelines produced from this study were summarised as:

(a) Location of the ignition source is critical to obtain the greatest pressure piling.
(b) The resistance to back flow through the restriction during burning in the second chamber is a major factor in determining if pressure piling will occur and to what degree.
(c) For most practical situations, pressure piling has a mechanical (movement of gas) limit rather than a thermodynamic limit: about 2758 kPa vis 4137 kPa.
(d) In most instances, some pressure piling will occur in a conduit box if ignition is in the conduit.
(e) Ignition by a sustained high energy arc will tend to reduce or eliminate pressure piling.
(f) A couple of measurements and a simple equation will tell us the best spark location for checking the potential of pressure piling in many of the enclosures we test for certification.

OTHER INCIDENCES OF PRESSURE PILING

One example of pressure piling examined by SIMTARS involved a flameproof motor which was being tested to the flameproof standard. The motor passed the dimensional requirements of AS2380.2 but when tested for flame containment it would consistently fail the flame transmission tests. After considerable review it was decided to remove an internal fan at one end of the motor, which was used for cooling as it appeared to provide suitable conditions for pressure piling. Without the fan the motor consistently passed the same tests it had previously failed and with fan reinstalled the motor could fail. After consultation with the manufacturer the fan design was modified with slots to eliminate the pressure piling which had resulted, in this case in transmission of an internal ignition. This case illustrates definitively the benefits of type testing of equipment, as opposed to dimensional correctness alone.

CONCLUSIONS

The occurrences of failures from pressure piling justify the requirement for type testing of flameproof equipment because these failures have occurred despite the equipment meeting the dimensional requirements of flameproof equipment standards. A corollary of this is that if equipment is modified on site in such a way that the free volume of the enclosure or the disposition of equipment in the enclosure is significantly changed, then the enclosure should be examined to ensure that its flameproof properties are not compromised. This is especially true for tightly packed enclosures. This does not necessarily mean an enclosure will need to be re-tested, but it gives the opportunity for mines to avail themselves of an independent assessment of the risk caused by the changes.

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