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Dynamic response and effect of apertures on explosion parameters of flameproof apparatus

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A R T I C L E I N F O

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A B S T R A C T

Explosion parameters for closed flameproof apparatus are changed when apertures like gap (e.g. push button) and porous structures (breathing element) are introduced on the cover or wall of the flameproof enclosures. Similarly, an interconnecting tube between two enclosures, results in significant change in explosion parameters. It is observed that the maximum explosion pressure, maximum rate of pressure rise and severity index are higher for enclosures with apertures on cover or body than that of enclosures without apertures. In case of two interconnected identical enclosures, the explosion parameters are increased in the secondary enclosure and higher than that of primary enclosure and also of isolated enclosure.

1. Introduction

Flameproof electrical equipment are designed and constructed for control and measurement applications in process industries and underground coalmines. A flameproof apparatus can simply be used for connection of electrical/electronic cables, and if necessary, it can be used with different control components like push buttons or switches. Use of push buttons/switches introduce gap between operating rod and cover of the enclosure for ON/OFF operation. In all circumstances, the flameproof apparatus should be able to withstand internal explosion pressure of a particular gas–air mixture as well as the internal flame should not transmit to the outer atmosphere through all joints, gaps and apertures (Indian Standard, 2007).

This gap should always be less than the maximum permissible value, otherwise the hot gas jet will ignite the explosive atmosphere outside the enclosure (Arntzen et al., 2014). The maximum explosion pressure developed inside the cylindrical enclosures depends on different parameters (Vishwakarma et al., 2014; Amyotte et al., 2002; Razus et al., 2006; Gieras and Klemens, 2009; Kindracki et al., 2007). Introduction of apertures around push buttons, rotary switches, shaft can help in reducing explosion pressures. Similarly, when a hooter is required to be placed inside the flameproof enclosure for alarm purpose; a breathing element can be fitted to the enclosure cover or body. The other purpose of such breathing element is to release moistured hot air from inside of the enclosure and breathe in fresh air from surrounding. A breathing element can be a sintered element in brass material with porous structure.

Some flameproof apparatus requires more than one enclosure to form a control panel or control station. For examples, flameproof apparatus having a terminal or connection box and a push button or indicator enclosure. Generally isolated enclosures are used for safety purpose such that, if a terminal enclosure is only required for connection, there is no chance of atmospheric contact of hot or energized components placed in the connected enclosure. These isolated enclosures are interconnected with sealed or moulded wire bushing. When this sealed wire bushing is removed, or a conductor wire from bushing is misplaced, an interconnection hole between two enclosures is formed. The hollow bushing is considered as interconnection tube.

The effect and use of porous structures for explosion venting are

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Nomenclature

h	height of cylindrical enclosure in cm
Ø	diameter of enclosure or tube in cm
V	volume of cylindrical enclosure in litre (l)
P_{max}	maximum explosion pressure in bar
$(dp/dt)_{ex}$	maximum rate of pressure rise in bar/sec,
K_G	severity index = $(dp/dt)_{ex} \times V^{1/3}$in bar-m/sec

reported earlier for safe design of flameproof enclosures (Hornig et al., 2013; Mecke et al., 2008).

Researchers (Razus et al., 2003; Phylaktou and Andrews, 1993; Singh, 1994; Benedetto et al., 2005; Wang et al., 2013; Wolfhard and Bruszak, 1960) have reported significant work on explosion propagation between linked vessels. However, the work reported was for a small and big enclosures interconnected together. In the present study, two cylindrical enclosures of equal volumes are used to perform experiment on interconnected enclosures.

Three different cases are chosen for experiments with the objective to study the effect of apertures (gap, porosity and tube) on explosion parameters in flameproof enclosures. The experiments are conducted at laboratory in 31% (v/v) hydrogen–air mixture. Flameproof enclosures are investigated with aperture on cover (in the form of push buttons), breathing element on the wall and interconnected hole between two enclosures.

It is observed that the maximum explosion pressure, maximum rate of pressure rise and severity index are higher for enclosures with apertures on cover or body (push buttons and breathing element) than that of enclosures without apertures. In case of two interconnected identical enclosures, the explosion parameters are increased in the secondary enclosure than that of primary enclosure and also of isolated enclosure.

2. Experimental setup

Four cylindrical flameproof enclosures, C1 (Ø = 15.5 cm, h = 10 cm, V = 1.888 l), two C2 (Ø = 11.5 cm, h = 6.5 cm, V = 0.675 l) and C3 (Ø = 17.5 cm, h = 12 cm, V = 2.887 l) are used to study the effect of apertures (gap, porous element, interconnecting tube) on explosion parameters. The material of construction of all the cylindrical enclosures is cast light aluminium alloy, LM6.

The enclosure C1 is used to perform experiments to study the effect of porous structures (breathing elements) on explosion parameters as shown in Fig. 1. Two identical breathing elements made of sintered brass material having porosity 40% and diameter 1.7 cm are used. The experiments are conducted on enclosure C1 with or without breathing elements.

To investigate the effect of apertures in the form of gap or slit on explosion parameters, enclosures C2 and C3 are used with two push buttons on the covers as shown in Fig. 2. Further, cover with push buttons was replaced with flat cover without push buttons. In both cases pressure–time histories are recorded. The operating rods are perforated in the push button assemblies in the covers of C2 and C3 to perform ON/OFF operation of the internal switching elements as shown in Fig. 2. The gap between the operating rod and cover of the enclosure is 0.015 cm and depth of engagement (also known as flamepath) is 2.5 cm.

To study the effect of tube on explosion parameters two identical enclosures C2 are used. When two C2 enclosures are interconnected using a bushing (tube) with a hole diameter 1.2 cm or 0.3 cm, a single entity, C2 − C2 is formed which is shown in Fig. 3.

In this experimental work a PC based dynamic pressure recording setup is used having Kistler pressure transducer and charge amplifier, type 6031 and 5018 respectively. The method of gas mixture preparation and filling of the mixture into the test enclosures were same as reported by Vishwakarma et al. (2014). In all explosion tests, 31% (v/v) hydrogen–air mixture is used.

For explosion tests, the hydrogen–air (31% v/v) mixture is filled into the test enclosure and left for at least two minutes undisturbed so that the mixture becomes quiescent. The gas–air mixture is ignited with the help of a spark plug/fuse and pressure–time histories are captured using the pressure recording setup as shown in Fig. 4. Tests are repeated at least three times with fresh gas–air mixture and maximum value of pressure recorded is termed as P_{max}. The explosion pressures reported in the paper are the absolute maxima of the pressure-time histories. The maximum rate of the pressure rise is the highest value of slope obtained by differentiating pressure-time plot for each test without smoothing, and the maximum value out of them is termed as $(dp/dt)_{ex}$ for a set of tests in a particular case. Severity index, K_G is also calculated for all the cases, which is the product of cube root of empty volume of the enclosure and maximum rate of pressure rise.

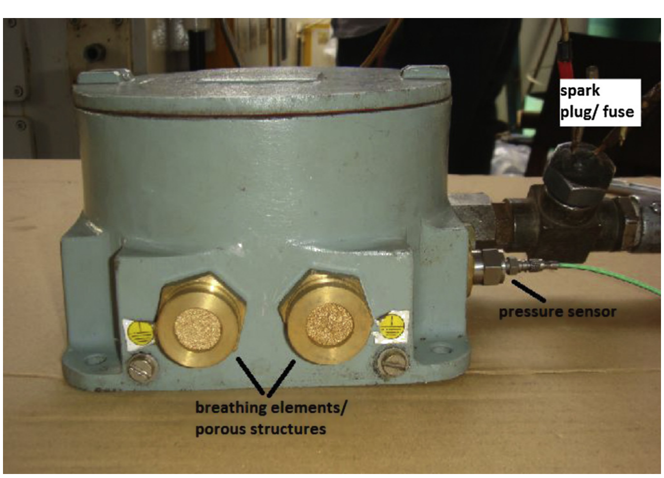

Fig. 1. Arrangement of breathing elements (porous structures) in enclosure, C1.

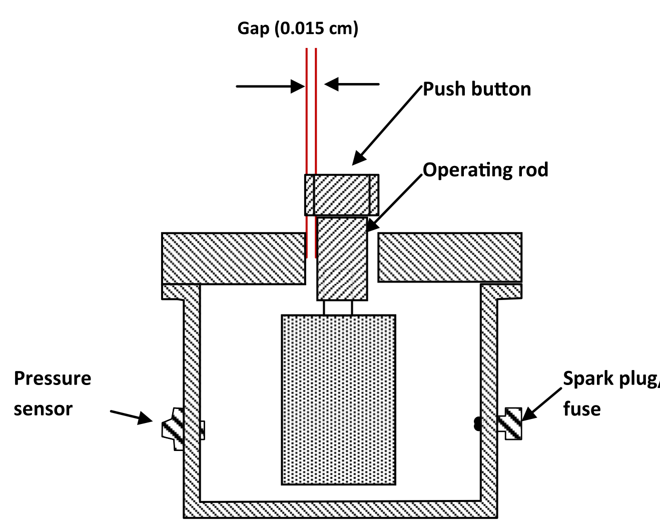

Fig. 2. Schematic diagram of aperture (gap) in the cover of flameproof enclosure.