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Considerations regarding the determination of explosion pressure at normal ambient temperature, compared to explosion pressure determination at ambient temperatures below – 40^0C, for flameproof enclosure

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Abstract. Flameproof enclosures (also known as explosion proof or Ex d enclosures) are critical safety components in hazardous environments where explosive atmospheres may exist. Their primary function is to contain an internal explosion without allowing the ignition to propagate to the external atmosphere. A key parameter in designing and certifying these enclosures is the maximum internal explosion pressure (P max) that the enclosure must withstand. This article explores the determination of explosion pressure under two specific ambient temperature conditions: 1. Normal ambient temperature range (typically – 200C to + 400C), and 2. Extremely low ambient temperatures, particularly below – 400C, which are often encountered in arctic or high altitude environments. The paper also presents some results obtained in our test laboratory, on a test sample (two configurations) with the explosion pressure determined for two different ambient temperatures (normal temperature and ambient temperature of -40 °C) and two different explosive mixtures (ethylene & hydrogen) selected according to standard IEC 60079-1.

1 Introduction

Flameproof enclosures (also known as explosion-proof or Ex d enclosures are critical safety components in hazardous environments where explosive atmospheres may occur. Their primary function is to contain an internal explosion without allowing the ignition to propagate to the external atmosphere. A key parameter in designinig and certifying these enclosures is the maximum internal explosion pressure (Pmax) that the enclosure must withstand [1-3].

This article explores the determination of explosion pressure under two specific ambient temperature conditions:

1. Normal ambient temperature (typically around – 20^0C to + 40^0C), and
2. Extemely low ambient temperatures, particularly below - 40^0C, which are often encountered in arctic or high altitude environments.

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2 General considerations

2.1 Explanation of the "flameproof" explosion protection technique

IEC 60079-1 Edition 7 [3] has the following definition for flameproof enclosure “d”:
enclosure in which apparatus that can ignite an explosive gas atmosphere is located and which is capable to resist to the pressure resulted during an internal explosion of an explosive mixture, and which prevents the transfer of the explosion to the explosive gas atmosphere surrounding the enclosure.

Is capable to resist to the pressure developed. Very high pressures can be generated due to an explosion inside a flameproof enclosure. Normal pressures are in the range of 200 to 1,000 kPa, but in some cases can rise even further. It is very important for an enclosure to withstand the particular pressures that it may encounter during its lifetime. The pressure created by the explosion within the enclosure is released to the atmosphere so that the enclosure is not permanently deformed in a way that can affect the integrity of the enclosure [4].

Which prevents the transmission of the explosion. As the explosive pressure within the enclosure forces its way through the gaps in the enclosure, the explosion flame is carried with it. If the energy of the explosion is not reduced as it forces its way through the gaps the explosion pressure front could have sufficient energy to ignite a surrounding explosive atmosphere. The specially designed gaps and joints in the enclosure are referred to as flame paths and their goal is to cool down the burnt gases to a value to which their temperature is smaller than the minimum ignition temperature of the surounding atmosphere outside the enclosure [4].

2.2 Pressure pilling

In the case of ordinary enclosures, the explosion pressure develops in a uniform manner through the enclosure. However, when an enclosure is so designed that it has some form of restriction between two or more parts of the enclosure things can be very different. When the explosion is initiated on one side of the restriction, the explosive atmosphere in the other side is compressed beforeit is ignited by the burning flame front. This results in a much higher pressure than in the case when there was no restriction between two parts of the enclosure [4].

IEC 60079-1 [3] has a definition for pressure piling:
results of an ignition, initiated in a compartment of an enclosure, of an explosive air-gas mixture, which has been compressed before, because of a first ignition in another compartment.

Pressure piling is important in theh case of Ex d electric motors that incorporate an air gap between the stator and rotor, because this provides the required conditions for pressure piling to be created. Other communication ways can be created as well, like ducts used for cooling purposes or open ways to the terminal box. The problem can be significantly exacerbated by low temperatures, according to the results obtained in the laboratory.

3 Regulatory principles

3.1 Determination of maximum explosion pressure (reference pressure)

The reference pressure is the maximum pressure, as compared to atmospheric pressure, that can be reached in the course of testing. A low-pass filter with a 3 dB point of 5 kHz ± 0.5

kHz is used for smoothing. In the case of apparatus used at ambient temperatures less than –20 °C, the maximum explosion pressure is measured by one of the following methods. In the case of all apparatus, the maximum explosion pressure is measured at a temperature which is not greater than the minimum ambient temperature. In the case of all apparatus, the maximum explosion pressure is measured at ambient temperature with the defined explosive mixtures used for testing but at a greater initial pressure. The pressure of the explosive mixtures used for testing *(P),* in kPa, is determined using the formula, with $T_{a,\,min}$ in °C [3]:

$$P = 100[293 / (T_{a,\,min} + 273)] \text{ kPa} \qquad (1)$$

In the case of other apparatus than electrical motors that have simple internal geometry with a volume less than 3 l, when they are empty, so that pressure-piling is improbable, the maximum explosion pressure is calculated at ambient temperature using the required explosive air-gas mixtures, but having a reference pressure increased with the “test factors for reduced ambient temperatures” given in Table 1. In the case of other apparatus than rotating electrical machines (like motors, generators and tachometers) that have simple internal geometry with volume less than 10 l, when they are empty, so that pressure piling is improbable, the maximum explosion pressure is measured at ambient temperature using the required explosive air-gas mixtures, but having a reference pressure increased with the “test factors for reduced ambient temperatures” given in Table 1 [3].

Table 1. Test factors for reduced ambient temperatures

Minimum ambient temperature °C	**Test factor**
≥ –20 (see Note)	1,0
≥ –30	1,37
≥ –40	1,45
≥ –50	1,53
≥ –60	1,62
NOTE: This applies in the case of equipment meant for use in the standard ambient temperature range mentioned in IEC 60079-0. Particular attention is required in the case of applications where the temperature inside the enclosure ismuch lower than the normal ambient temperature.	

The test consists of igniting an air-gas explosive atmosphere in the enclosure and measuring the pressure generated by the explosion. The air-gas explosive atmosphere is ignited by one or several ignition sources. If the enclosure has a component that generates sparks which are able to ignite the air-gas explosive atmosphere, the component can be used to generate the explosion (but it is not necessary to generate the maximum power for which the component is meant for). The pressure generated during the explosion is measured in the case of each test. The places where the ignition sources are located, as well as the places to locate the pressure transducers are decided by the laboratory, in order to determine the arrangement that can produce the greatest pressure. [3]

The tests required to be carried out and the air-gas explosive atmosphere needed for testing, in volumetric ratio with air and at atmospheric pressure, are the following:

- apparatus of Group I: three tests with (9,8 ± 0,5) % methane;
- apparatus of Group IIA: three tests with (4,6 ± 0,3) % propane;

- apparatus of Group IIB: three tests with (8 ± 0,5) % ethylene;
- apparatus of Group IIC: five tests with (14 ± 1) % acetylene and five tests with (31 ± 1) % hydrogen.

3.2 Overpressure testing – Method one (static)

It is required to apply the following relative pressure:

- 1,5 times the maximum explosion pressure; or
- 4 times the maximum explosion pressure in the case of enclosures which are not routine overpressure tested; or
- 3 times the maximum explosion pressure in the case of enclosures where a batch test is used instead of the routine overpressure testing; or at the pressures listed in Table 2, when the determination of the maximum explosion pressure was not possible because of the small size of the apparatus [3].
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Table 2. Relative pressures for small equipment

Volume cm^3	**Group**	**Pressure**[a] kPa
≤10	I, IIA, IIB, IIC	1 000
>10	I	1 000
>10	IIA, IIB	1 500
>10	IIC	2 000
In the case of apparatus which is used at an ambient temperature below –20°C, the above mentioned pressures will be increased by the required test factors listed in Table 1.		

The pressure is applied for at least 10 s.

There is only one test to be carried out on each sample. The result of the overpressure test is considered successful if the test result is in accordance with article 15.2.2.2 of IEC 60079-1 and if no leakage is discovered through the walls of the enclosure [3].

A hydraulic agent (usually water-oil emulsion) is used in the case of these tests. If an environment (such as air or inert gas) which can be compressed is used, destruction of the enclosure can lead to the injury of personnel and not only.

3.3 Overpressure test – Second method (dynamic)

The dynamic tests are achieved so that the maximum pressure applied to the enclosure is 1,5 times the maximum explosion pressure.

When the tests are achieved using the mixtures described in 15.2.2.2 of IEC 60079-1, these can be precompressed in order to generate an explosion pressure of 1,5 times the maximum explosin pressure.

The test is carried out only one time, but in the case of apparatus of Group IIC each test is done three times with each gas.

The overpressure test is successful if the result of the test is in accordance with article 15.2.1 of IEC 60079-1 [3].

4 Case study

4.1 Testing program

It was necessary to devise an experimental setup that could check the approach permitted by the standard of increasing the initial pressure, in order to account for the low ambient temperature. The experimental setup could be used as a single chamber or with two chambers separated by an orifice sized to induce pressure piling to occur.

Figure 1 shows an exploded view of the design of the artefact with both chambers and the orifice.

The experimental setup or Test Sample (see Figure 1) consists of two cylindrical compartments of different lengths as well as an orifice. Additionally, two blank flanges are included, each equipped with five test holes of different thread forms.

Fig. 1. Exploded view of Test Sample

The following is a list of components (see also Figure 2 and Figure 3):

– Pipe A: 1 x pipe section including 2 x connecting flanges with a total length of 250 mm
– Pipe B: 1 x pipe section including 2 x connecting flanges with a total length of 500 mm
– 2 x blind flanges with test holes
– 1 x orifice: diameter of the orifice hole (15 ± 0.3) mm
– 4 x flange gaskets
– 24 x connecting screws + 24 x nuts
– 8 x locking screws + 8 x sealing rings.

Test method used

The explosion pressure was determined with the Test Sample for two different configurations (single chamber and combination of both chambers with orifice), two different ambient temperatures (normal temperature and ambient temperature of -40 °C) and two different explosive mixtures (ethylene & hydrogen) selected according to IEC 60079-1. To increase the statistical significance, five tests were made for each case. The tests with the ambient temperature of -40 °C were performed according to the usual test method used in the laboratory (in accordance to clause 15.2.2.1 of IEC 60079-1):

- at normal ambient temperature using the defined test mixture(s), but at increased pressure [3].

On the basis of two configurations of the Test Sample, two explosive mixtures, two ambient temperatures and five ignitions each, a total of 40 explosion tests were carried out in the laboratory.

Configurations of Test Sample and measurements

The configurations of the Test Sample to perform the tests were as follows:

Configuration a)

- Pipe A
- Five ignition tests with explosive mixture (1) (ethylene 8 % ± 0.5 %) at normal ambient temperature (ignition side 1)
- Five ignition tests with explosive mixture (2) (hydrogen 31 % ± 1 %) at normal ambient temperature (ignition side 1)
- Five ignition tests with explosive mixture (1) (ethylene 8 % ± 0.5 %) for use at an ambient temperature of - 40 °C (ignition side 1)
- Five ignition tests with explosive mixture (2) (hydrogen 31 % ± 1 %) for use at an ambient temperature of - 40 °C (ignition side 1).

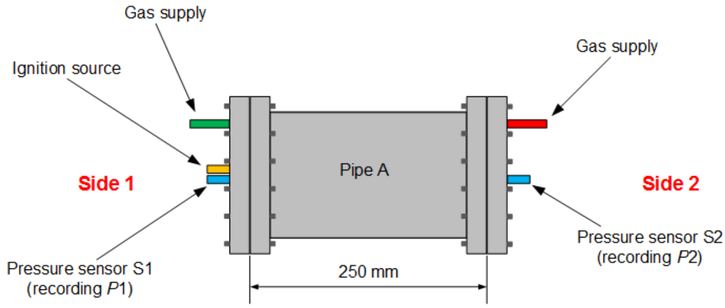

Fig. 2. Configuration a)

Configuration b)

- Pipe A combined with Pipe B and orifice
- Five ignition tests with explosive mixture (1) (ethylene 8 % ± 0.5 %) at normal ambient temperature (ignition side 2)
- Five ignition tests with explosive mixture (2) (hydrogen 31 % ± 1 %) at normal ambient temperature (ignition side 2)
- Five ignition tests with explosive mixture (1) (ethylene 8 % ± 0.5 %) for use at an ambient temperature of - 40 °C (ignition side 2)
- Five ignition tests with explosive mixture (2) (hydrogen 31 % ± 1 %) for use at an ambient temperature of - 40 °C (ignition side 2).

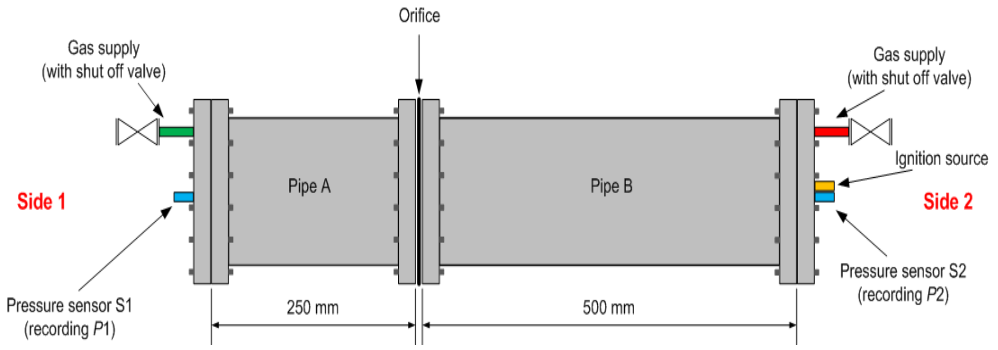

Fig. 3. Configuration b)

4.2 Results obtained

Next are shown some of the most important results (hydrogen – air mixtures which resulted in highest pressures recorded), obtained during the researches carried out in our laboratory:

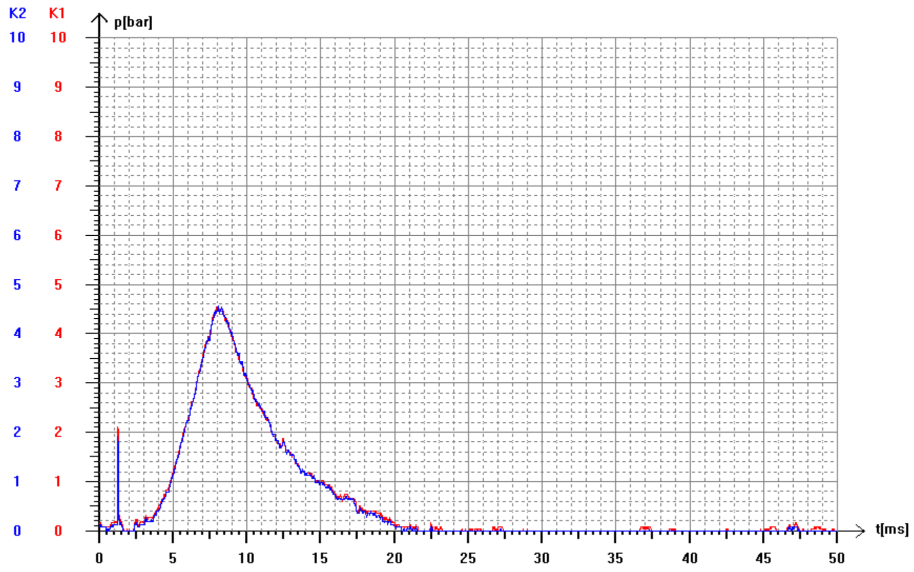

Fig. 4. Configuration a) (Pipe A – Test 10) -> hydrogen -> maximum explosion pressure at normal ambient temperature

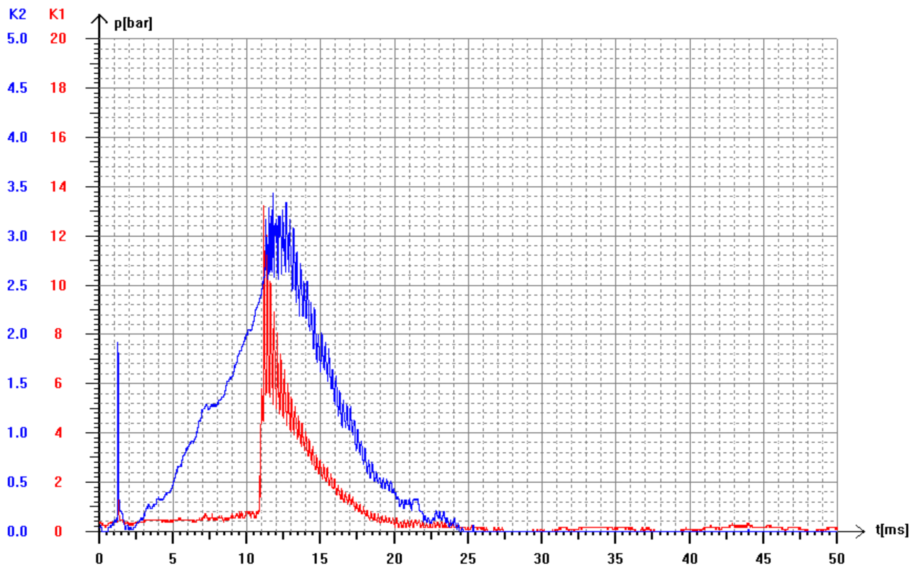

Fig. 5. Configuration b) (Pipe A + Pipe B – Test 8) -> hydrogen -> maximum explosion pressure at normal ambient temperature

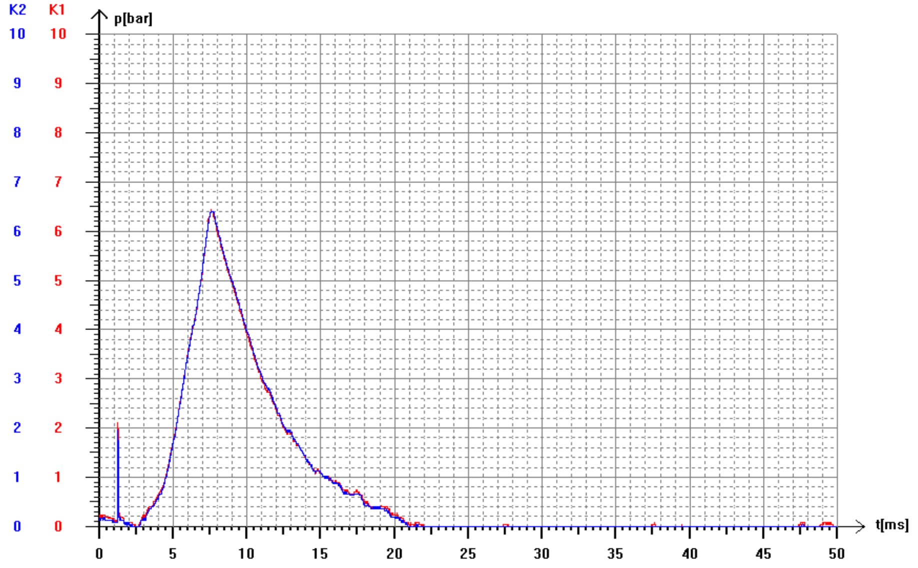

Fig. 6. Configuration a) (Pipe A – Test 7) -> hydrogen -> maximum explosion pressure at ambient temperature of - 40 °C

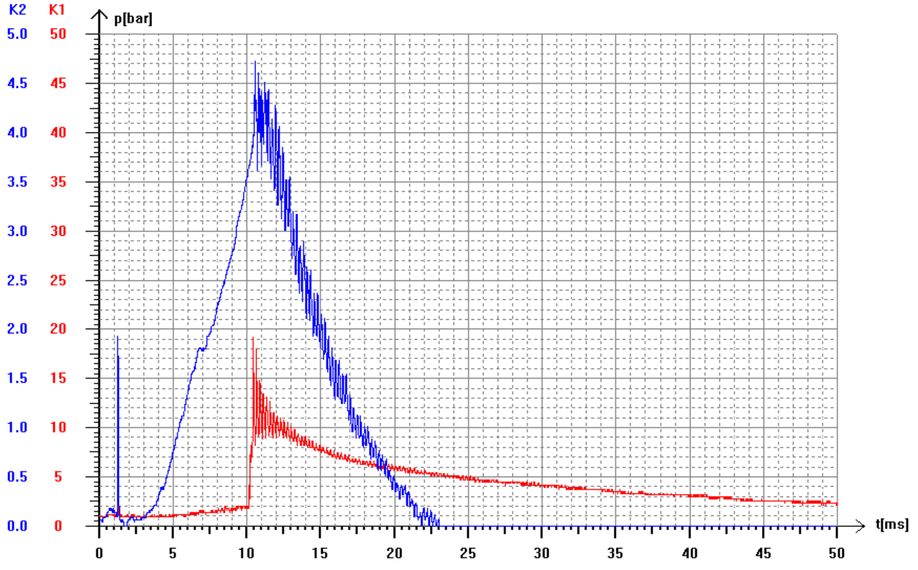

Fig. 7. Configuration b) (Pipe A + Pipe B – Test 9) -> hydrogen -> maximum explosion pressure at ambient temperature of - 40 °C

4.3 Discussions

For the purpose of this article, we have selected the pressure curves giving the highest pressures for both Configuration a) and Configuration b) and for both normal ambient temperature as well as for ambient temperatures of - 40 °C (using hydrogen – air mixture for which the maximum pressures were higher than in the case of ethylene – air mixtures).

- In the case of configuration a), with no pressure pilling occuring, the maximum explosion pressure obtained for – 40^0C, was 6.4 bar, compared to 4.6 bar maximum explosion pressure at normal ambient temperature. Also, the rate of rise of maximum explosion pressure was higher when the test was conducted for – 40^0C ;
- In the case of Configuration b) (Pipe A + Pipe B) when pressure pilling was an issue, the maximum explosion pressure obtained for – 40^0C, was almost 20 bar, compared to aprox. 13 bar maximum explosion pressure at normal ambient temperature. Also, the rate of rise of maximum explosion pressure was higher when the test was conducted for – 40^0C.

5 Conclusions

While explosion pressure determination at normal ambient temperatures provides reliable baseline data for flameproof enclosure design, conditions for - 40^0C introduce several additional complexities. Gas behaviuor, igntion dynamics and material responses all change under cryogenic conditions. We have concluded, following these researches that in the case of flameproof enclosures where pressure pilling is an issue (such as is the case for electric motors, for example), manufacturers must consider these factors when certifying equipment for extreme environments.

Also, in the case of flameproof enclosures that involve simpe geometry and where pressure pilling is not an issue to be considered, eventhough explosion pressure at extremely low temperatures may not be much higher than at room temperature, the structural risk to the enclosure may increase due to material degradation. Therefore, rigorous low-temperature testing and conservative design coefficients are essential for safe operation in such environments.

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