# Accessible technical solution for normal construction apparatus usage in Ex classified areas

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*Abstract:* - This paper intercession is due to an undesirable penury state regarding eligible technical equipment for use in Ex classified areas. This fact competed with the negative dynamic of material possibilities leads to an apparent lack of interest regarding protection to explosion. As a solution to the identified problem, the authors propose the use of normal construction technical equipment adapted according to prescriptions of "$p_z$" pressurized enclosure protection type. This intercession presents a good estimated level of tolerance to customer and will lead to the decrease of explosion risk level due to technical equipment and lower acquisition, maintenance and repair specific costs.

*Keywords: - Ex classified areas, Ex apparatus, pressurization, autonomy time, purging, loss compensation*

## 1 Introduction

Electrical apparatus intended to operate in potential explosive atmospheres is divided in [5], [6]:

- Group I – electrical apparatus for firedamp mines;
- Group II – electrical apparatus for places with potential explosive atmosphere, other than firedamp mines.

Electrical apparatus of Group II may be subdivided according to the nature of potential explosive atmosphere for which is provided.

For certain types of protection, for example "d" flameproof enclosure, "i" intrinsic safety, electrical apparatus from Group II is subdivided in IIA, IIB and IIC as they are specified in specific European Standards regarding the types of protection [6].

Equipment marked IIB corresponds applications that require equipment of Group IIA. Similarly, equipment marked IIC corresponds applications that require equipment of Group IIA or IIB.

Electrical apparatus may be tested for a particular explosive atmosphere. In this case it must be certified and marked accordingly by the manufacturer.

In the environment with potential explosive atmospheres is important to take into account the correlation between the maximum surface temperature and ignition temperature of flammable substance [4].

Another important factor to be considered is the frequency of occurrence for explosive atmosphere into an area.

The area classification considering this factor distinguishes three types of zones:

Zone 0 - areas in which explosive atmosphere exists permanently or for long periods.

Zone 1 – areas where explosive gas atmosphere it is likely to occur during normal operation of technological facilities producing flammable gases or dust.

Zone 2 - area where an explosive gas atmospheres is not likely to occur in the normal operation of technological facilities and where, if it still appears, it is likely to occur only rarely and only for a short period of time due to expected defects.

Zoning is important for choosing electrical equipment. It should be noted that proper zoning is based on the source of release criteria and quality of ventilation.

An incorrect zoning (extended) leads to mandatory use of technical equipment protected to explosion, which is more expensive (for the purchase and operation) than the normal construction equipment [8].

In zone 2, where the danger occurs only rarely, the equipment of category 3 can be used, according to ATEX Directive 94/9/EC [10] taken over in Romania by HG 752/2004 [7].

## 2 Short historical of pressurized type of protection „p”

The initial stages of the pressurized enclosure “p” type of protection can be traced back to 1930s. The VDE 0170/0171:1943 already described the type of protection “fremdbelüftung” (forced air ventilation) that contains the fundamental principles of today’s pressurized enclosure [2].

The changes to the requirements in the European Standards on pressurization which arose during the transition to EC Directive 94/9/EC and the harmonization of regional standards at IEC level are somewhat more extensive than those for other types of protection. The technology of the pressurization usually results in equipment of Category 2 (for use in Zone 1) or 3 (for use in Zone 2). It cannot be used for Category 1 equipment (for use in Zone 0). For Zone 2, so far the VDE 0165: 1991 specify German national requirements for the simplified pressurized enclosure. On an international level, the IEC standard 60079-2 formulates requirements for the simplified pressurization with the defined type of protection ‘p’ [3].

The European Standard EN 50016 has been applicable to Zone 1 equipment since 1995 until June 2007. This has the technical content largely equivalent to that in IEC 60079-2, type of protection ‘p’. Only the special features of the equipment marking and a few other requirements in the EC Directive have been further incorporated. It has already been established that this standard meets the essential safety requirements in Directive 94/9/EC.

As already stated, the type of protection specified in EN 50016, pressurized apparatus ‘p’, in the main corresponds to design ‘px’ introduced by IEC 60079-2 (EN 60079-2) [3]. The most important constructional requirements for pressurized systems remain the same. For example, the tightness, accessibility and mechanical strength of the pressurized enclosure are specified. The internal structure and the assignment of the equipment must permit trouble-free and complete purging of the enclosure during the purging phase. If apparatus which produces sparks during operation with an operating current of more than 10 A and a rated operational voltage of more than 275 V AC – or 60 V DC – are installed, spark and particle barriers must be provided for the outlets under precisely defined conditions. All actuators for control and signaling devices and inspection windows must, if they are fitted in the enclosure of the Ex ‘p’ cabinet, be subjected to thermal endurance test to cold and heat in accordance with EN 60079-0, followed by an impact test. Following that, the required IP degree of protection must be guaranteed [3].

Depending upon the type of protection pressurization ‘px’, ‘py’ or ‘pz’, introduced together with IEC 60079-2:2001 (EN 60079-2:2004), graduated safety requirements are specified for the properties and functions of the equipment pressure and flow rate monitors used to monitor door status, etc. The manufacturer must provide the operator with all the information necessary for safe operation in the form of state diagrams, flow diagrams, etc. in a detailed instruction manual. The upper and lower limits and their tolerances for safety requirements should be specified by the manufacturer and noticed to the user. The functional sequences of the safety devices and the required response in case of malfunctions or faults should also be described.

## 3 Requirements for apparatus eligible for Zone 2

Category 3 comprises equipment designed to be able to operate in accordance with operating parameters established by the manufacturer and ensuring a normal level of protection [1].

The apparatus placed in this category ensures the expected protection level during normal operation.

The apparatus classified in category 3 must comply with the following additional requirements [9][13][14]:

- Be designed and constructed so as to prevent foreseeable ignition sources which may occur in normal operation;
- The surface temperatures shall not exceed the maximum surface temperatures in the provided operating conditions set. In exceptional cases, higher temperatures are permitted if the manufacturer takes additional measures of protection. The temperature class shall be based on the hottest external surface of the enclosure.
- Be designed and constructed so that mixtures of air / gas can not be ignited by foreseeable ignition sources which may exist under normal operating conditions;
- The apparatus, including cable entries and connecting pieces, must be designed, so as to meet the requirements of applicable specific standards.

The specific design criteria, for the type of protection pressurization “pz” are presented in Table 1.

Table 1 – Design criteria based upon protection type [11]

| Design criteria | Type $p_z$ with indicator | Type $p_z$ with alarm |
|---|---|---|
| Degree of enclosure protection according to IEC 60529 or IEC 60034-5 | IP4X minimum | IP3X minimum |
| Resistance of enclosure to impact | According IEC 60079-0 | Half the value according IEC 60079-0 |
| Verifying purge period | Time and flow marked | Time and flow marked |
| Preventing incandescent particles from exiting a normally closed relief vent into a zone 1 area | Spark and particle barrier required, unless incandescent particles not normally produced | Spark and particle barrier required, unless incandescent particles not normally produced |
| Preventing incandescent particles from exiting a normally closed relief vent into a zone 2 area | No requirement | No requirement |
| Preventing incandescent particles from exiting a vent open to a zone 1 area in normal operation | Spark and particle barrier required | Spark and particle barrier required |
| Preventing incandescent particles from exiting a vent open to a zone 2 area in normal operation | Spark and particle barrier required, unless incandescent particles not normally produced | Spark and particle barrier required, unless incandescent particles not normally produced |
| Door/cover requiring a tool to remove | Appropriate warning | Appropriate warning |
| Door/cover not requiring a tool to remove | No requirement | No requirement |
| Internal hot parts that require a cool-down period before opening enclosure | Appropriate warning | Appropriate warning |
| There is no requirement for spark and particle barriers since in abnormal operation, where the relief vent opens, it is unlikely that the external atmosphere is within the explosive limits.<br><br>There is no requirement for marking or tool accessibility on a pz enclosure since in normal operation the enclosure is pressurized with all covers and doors in place. If a cover or door is removed, it is unlikely that the atmosphere is within the explosive limits. | | |

**Safety provisions and safety devices for static pressurization [11]**

All safety devices used to prevent electrical apparatus protected by static pressurization causing an explosion, shall themselves not be capable of causing an explosion and, if the safety device is electrically operated, it shall be protected by one of the recognized types of protection or shall be mounted outside the hazardous area.

The protective gas shall be inert. The concentration of oxygen after filling with inert gas shall be less than 1 % by volume.

Internal sources of release are not permitted.

The pressurized enclosure shall be filled with inert gas in a non-hazardous area using the procedure specified by the manufacturer.

One automatic safety device for type pz shall be provided to operate when the overpressure falls below the minimum value specified by the manufacturer. It shall be possible to check the correct operation of the devices when the apparatus is in service. The automatic safety devices shall only

be capable of being reset by the use of a tool or a key.
The purpose for which the automatic safety devices are used (that is, to disconnect power or to sound an alarm or otherwise ensure safety of the installation) is the responsibility of the user.
Electrical apparatus within the pressurized enclosure that may be energized when type of protection "p" is not in operation shall be protected by one of the other types of protection.
The minimum overpressure shall be greater than the maximum pressure loss in normal service measured over a period not less than 100 times the time necessary for the cooling of enclosed components, with a minimum of 1 h. The minimum level of overpressure shall not be less than 50 Pa above the external pressure under the most onerous conditions specified for normal service.

Also, there is some information that the user should know when installing or operating the pressurized equipment.
It is essential for safety that information about proper installation of the pressurization system be provided to the user. In those cases where conditions of use require the user to install safety devices or to provide protection not normally required, the manufacturer should mark the unit as needed. The description documents should contain all necessary information required by the user to ensure conformity with the requirements stipulated in standards.
Specific issues that the manufacturer should address as appropriate are as follows [11]:

a) Ducting of protective gas

- Location of inlet

Except for cylinder-supplied gases and some group I applications, the point at which the protective gas enters the supply duct(s) should be situated in a non-hazardous area.
For group I applications where the protective gas enters the supply ducts from a hazardous area, the following precautions should be taken:
a) two independent firedamp detectors should be fitted at the discharge side of the fan or compressor, each arranged to automatically disconnect the electricity supply to the pressurized enclosure if the concentration of firedamp exceeds 10 % of the lower explosive limit;
b) the time taken to achieve automatic disconnection should not be greater than one half the transit time for the protective gas to flow from the detection point to the pressurized enclosure;
c) in the event of automatic disconnection, the pressurized enclosure should be repurged before the electricity supply is restored. The purging time should not start until the firedamp concentration at the source of protective gas falls below 10 % of the lower explosive limit.

- Ducting between pressurized enclosure and inlet

The intake ducting to a compressor should not normally pass through a hazardous area.
If the compressor intake line passes through a hazardous area, it should be constructed of non-combustible material and protected against mechanical damage and corrosion.
Adequate precautions should be taken to ensure that the ducting is free from leaks in case the internal pressure is below that of the external atmosphere. Additional protective measures, for example, combustible gas detectors, should be considered to ensure that the ducting is free of flammable concentrations of gas or vapour.

- Outlets for protective gas

Ducts for exhausting the protective gas should preferably have their outlets in an area which would, apart from the area in close proximity to the outlets, be non-hazardous, unless particle barriers have been provided by the manufacturer or added by the user.

- Additional purge time to account for ducting

The purge duration should be increased by the time necessary to purge the free volume of those associated ducts which are not part of the certified apparatus by at least five times their volume at the minimum flow rate specified by the manufacturer.

b) Power for protective gas supply

The electrical power for the protective gas supply (blower, compressor, etc.) should be either taken from a separate power source or taken from the supply side of the electrical isolator for the pressurized enclosure.

c) Static pressurization

If the overpressure falls below the minimum specified, the pressurized enclosure should be removed to a non-hazardous area before refilling.

d) Enclosures with a containment system

The maximum pressure and flow of the flammable substance into the containment system should not exceed the ratings specified by the manufacturer.
Additional precautions may be necessary if an explosive mixture may possibly form due to air penetration into the containment system.

Adequate precautions should be taken to prevent adverse operating conditions that may damage the containment system. The description documents should explain these conditions such as vibration, thermal shock and maintenance operations when doors or access covers of the pressurized enclosure are open.

A flow switch may be required to stop the flow of the flammable substance, for example, if it could be ignited by a hot internal surface and the positive internal pressure is relied upon to prevent release from the containment system.

Additional precautions may be necessary if the abnormal release may adversely affect the external area classification.

e) Enclosure maximum overpressure

The user should limit the pressure as specified by the manufacturer.

## 4 Proposed solution [1]

By a careful analysis of new concepts of protection for electrical equipment which carries a sufficient security level for use in zone 2, it can be concluded that the following type of protection is eligible:

pz - ELECTRICAL APPARATUS PROTECTED TO EXPLOSION BY PRESSURIZATION IN ACCORDANCE WITH SR EN 60079-2

This type of protection reduces the classification within the pressurized enclosure from zone 2 to a non-dangerous area. This concept of protection meets the requirements for category 3 of equipment used in Zone 2.

This type of protection is easy for the user because the normal construction equipment can be adapted with minimal costs and within a short time for use in Ex environment, zone 2 (fig.1).

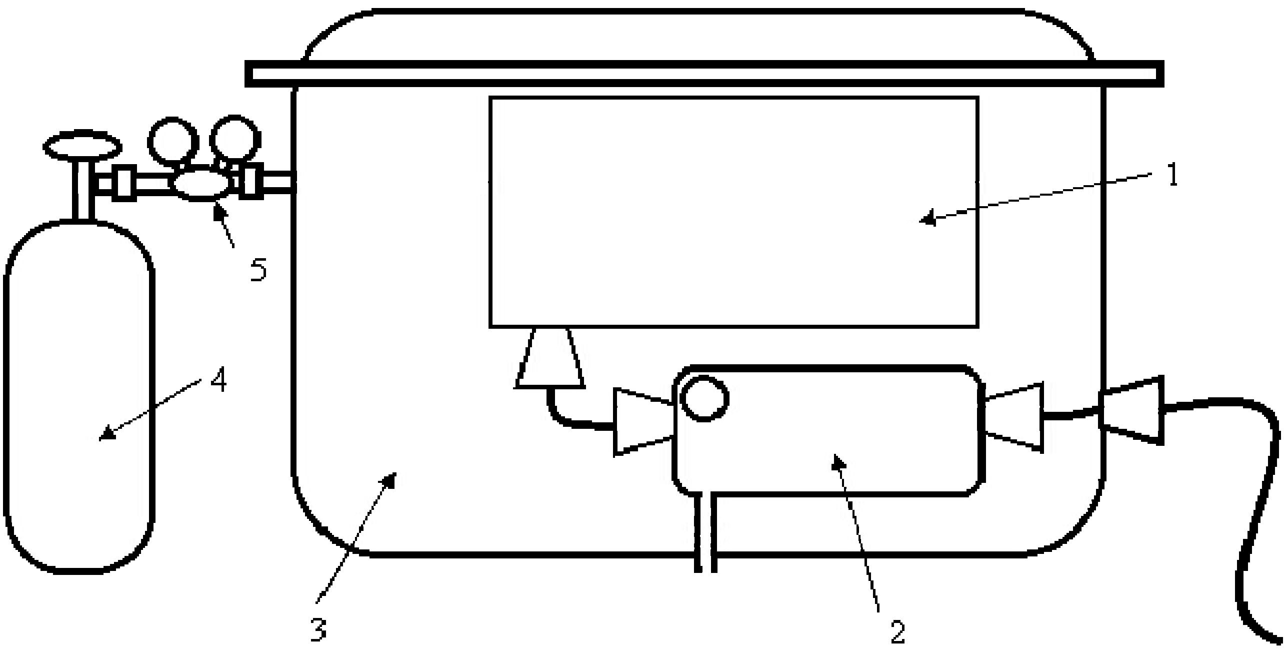


Fig.1 Equipment in normal construction explosion protected by pressurization

Legend:
1. Apparatus in normal construction
2. Manometer with contact
3. Pressurized enclosure
4. Protection gas
5. Pressure regulator

# 5 Theoretical model for the autonomy calculus of "pz" pressurized equipment by loss compensation method

Taking into account the method of protection with loss compensation, necessary changes involve the inclusion of the necessary equipment to be protected in a housing connected to a cylinder with protective gas through a pressure regulator which guarantees a minimum overpressure of 1 mbar.

Taking in consideration the theoretical model proposed in (1), the weight rate lost through enclosure's leaks is [12]:

$$W = 0{,}8 \cdot A \cdot \sqrt{2 \cdot \frac{k}{k-1} \cdot \frac{M \cdot p_{int}^{2}}{R \cdot T_1} \cdot \left[ \left( \frac{p}{p_1} \right)^{\frac{2}{k}} - \left( \frac{p}{p_1} \right)^{\frac{k+1}{k}} \right]} \quad (1)$$

$$P_{crit} = \frac{p}{\left( \frac{2}{k+1} \right)^{\frac{k}{k-1}}} \quad (2)$$

where:

- A – gas release area;
- $p_{crit}$ – critical pressure;
- p – atmospheric pressure;
- k – adiabatic exponent;
- M – molar mass of gas;
- R – general gas constant;
- $T_1$ – absolute ambient temperature;
- $p_1$ – minimum overpressure required;
- $p_{int}$ = p + minimum overpressure required;
- $p_1 = p_{crit}$ if $p_{int} > p_{crit}$ , complementary $p_1 = p_{int}$

Estimated period of autonomy can be calculated according to:

$$t = \frac{M \cdot (p_B - p_{\min}) \cdot v_B}{W \cdot R \cdot T} \quad (3)$$

where:
- $p_B$ - gas pressure in the cylinder;
- $p_{min}$ - minimum gas pressure allowed to the pressure regulator entry;
- $v_B$ - cylinder volume;
- W - weight rate calculated with above relation;
- M - molar mass of protection gas;
- R - general gas constant;
- T - ambient temperature;

Taking in consideration the above relations it can be seen that the system autonomy can be calculated more simply by the formula:

$$t = \alpha \sqrt{M} \, \frac{(p_B - p_{\min}) \cdot v_B}{A} \quad (4)$$

$\alpha$ parameter results from the relation below and does not depend on the type of protection gas.

$$\alpha = \frac{1}{0{,}8 \cdot \sqrt{2 \cdot (p + p_s)^2 \cdot R \cdot T \cdot \frac{k}{k-1} \cdot \left[ \left( \frac{p}{p_1} \right)^{\frac{2}{k}} - \left( \frac{p}{p_1} \right)^{\frac{k+1}{k}} \right]}} \quad (5)$$

where: $p_s$ – minimum overpressure required

The other parameters of relation (5) have been explained in previous relations.

The importance of cylinder parameters can be supplementary observed, in order to create pressurization ($p_B$, $p_{min}$, $v_B$).

Relation (4) underlines practically the dependency to the type of protective gas.

In order to calculate the pressurized equipment "$p_z$" autonomy time, when using liquefied gas cylinders in loss compensation method, the direct formula (1) is used, taking care of relation (6) and observations mentioned in relations (8) and (9).

$$t = \frac{m_B}{W} \quad (6)$$

Where:

$m_B$ – mass of the liquefied gas in the cylinder;
W – weight rate lost.

The theoretical model provides the necessity of identifying heavy molecule protective gases.

Based on this criterion, the carbon dioxide represents the favorite of the protective gases currently used.

# 6 Theoretical model for calculus of compressed-air consumption in case of "$p_z$" pressurized equipments by loss compensation method

The various industrial platforms have, in technological purposes, compressed-air networks that can be used as needed, also, for pressurization of normal construction equipments by loss compensation method.

Thus, the opportunity created by the pre-existence of the compressed-air network is exploited.

Unlike the previous theoretical model, the concept of autonomy became senseless, but formula of consumed compressed-air flow rate is needed in

order to maintain pressurization.
Even if this intercession explicitly refers to pneumatic networks, the theoretical model can be successfully applied also, in case of network availability, together with other types of inert gases like carbon dioxide, nitrogen.
The mass conservation principle is taken into account for the gas that suffers an isotherm expansion by pressure reduction throughout a pressure regulator. The inert gas (or air) quantity is further transferred to $p_z$ enclosure and then discharged in its various leakinesses.
The consumed compressed-air volume flow to supply $p_z$ pressurized enclosure is given by relation (7).

$$Q_V = \frac{W \cdot R \cdot T}{p_C \cdot M} \qquad (7)$$

where:

W – weight rate lost through leakinesses and determined according (1);
$P_c$ – compressed-air pressure;
M – molar mass of the gas;
R – gases universal constant;
T – ambient temperature.

If the expression in formula (1) is analyzed it can say that this depends practically only on ambient temperature, molar mass of the gas and surface of enclosure's leaknesses.
By rewriting formula (1), results the mass specific loss (or mass flux) of protective gas, given in relation (8).

$$\frac{W}{A} = 0{,}8 \cdot \beta \cdot \sqrt{\frac{M}{T}} \qquad (8)$$

where

$$\beta = \sqrt{2 \cdot \frac{k}{k-1} \cdot p_{\text{int}}{}^2 \cdot R \cdot \left[\left(\frac{p}{p+p_{\text{int}}}\right)^{\frac{2}{k}} - \left(\frac{p}{p+p_{\text{int}}}\right)^{\frac{k+1}{k}}\right]} \qquad (9)$$

By taking into account formulas (7) and (8), results formula (10)

$$\frac{Q_v}{A} = 0{,}8 \cdot \frac{\beta}{p_c} \cdot \sqrt{\frac{T}{M}} \qquad (10)$$

# 7 Numerical simulations of theoretical models

In order to calculate autonomy time for gases that haven't suffered state transition at compression, the following values for input parameters were taken into account:

Table 2

| Symbol | Value | MU |
|---|---|---|
| A | 0.1 | $mm^2$ |
| p | 0.987 | bar |
| $p_s$ | 0.0005 | bar |
| $p_{int}$ | $p+p_s$ | bar |
| k | 1.2 | - |
| M | 4 ($He_2$) | - |
| R | 8,31451 | J/(mol*K) |
| T | 60 | °C |
| $p_B$ | 100 | bar |
| $p_{min}$ | 1.1 | bar |
| $v_B$ | 0.001 | $m^3$ |
| α | 1,37994E-04 | |
| t | 17,48 | days |

The autonomy time resulted from table 2, has a small value, which indicates necessity for identifying of another solution for pressurization or other protective gas.
Figures 2 and 3 present the autonomy time for pressurization system $p_z$ with nitrogen (red), air (blue) and helium (pink). A high dependency can be observed between autonomy time and type of protective gas and a much lower dependency relative to ambient temperature.
In these diagrams the input parameters values, except temperature and molar mass, are according table 2.

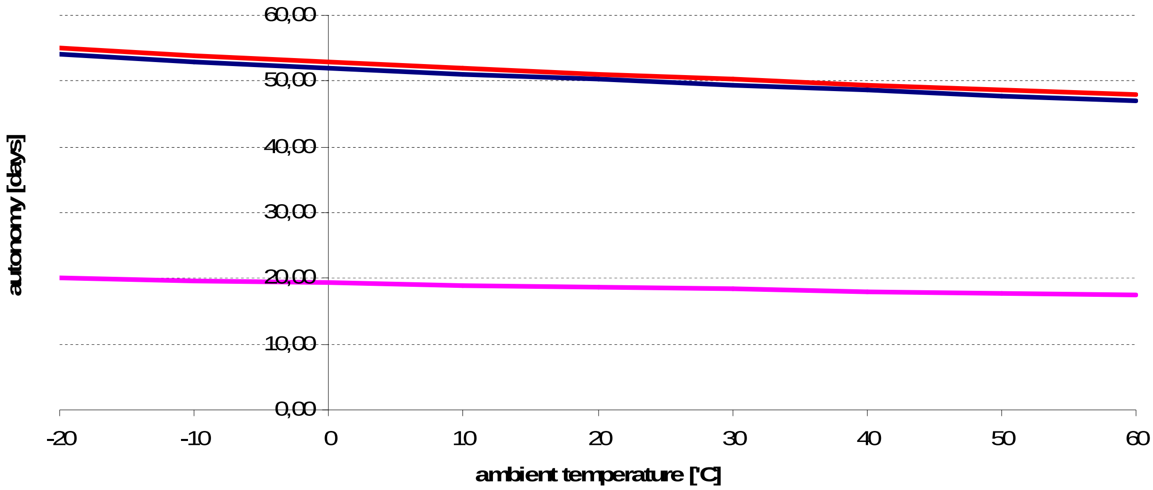


Fig. 2 Autonomy time function of ambient temperature for nitrogen (red), air (blue) and helium (pink)

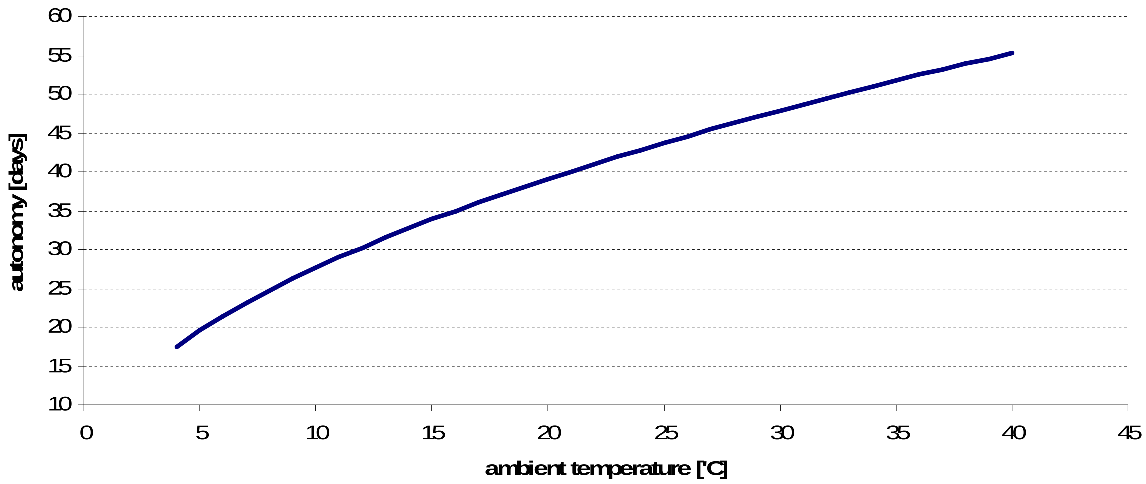


Fig. 3 Autonomy time function of molar mass of the protective gas (Tamb=60'C)

Estimated autonomy time in case of gaseous protective gas in the cylinder has relatively low values (Table 3). Taking into account that at higher pressures some gases are in liquid state, the calculus model presented in relation (6) shall be used.

Table 3

| Symbol | Value | MU |
|---|---|---|
| A | 0.1 | $mm^2$ |
| p | 0.987 | bar |
| $p_s$ | 0.0005 | bar |
| $p_{int}$ | $p+p_s$ | bar |
| k | 1.2 | - |
| M | 44 ($CO_2$) | - |
| R | 8,31451 | J/(mol*K) |
| T | 60 | °C |
| $m_B$ | 1 | Kg |
| W | 1,002E-06 | kg/s |
| t | 11,55 | days |

In case of industrial platforms provided with compressed-air networks, compressed-air can be used, as needed, to pressurize equipments in normal construction by loss compensation method (Table 4). Supplementary, because the equivalent surface of enclosure leakinesses is not precisely known, relation (10) will be used.
Regarding compressed-air consumption, the results show the advantage of using high pressures in compressed-air networks (Fig. 4).

Table 4

| Symbol | Value | MU |
|---|---|---|
| $p$ | 0.987 | bar |
| $p_s$ | 0.0005 | bar |
| $p_{int}$ | $p+p_s$ | bar |
| k | 1.2 | - |
| M | 29 (aer) | - |
| R | 8,31451 | J/(mol*K) |
| T | 60 | °C |
| $\beta$ | 9058,35 | - |
| $p_c$ | 5 | bar |
| $Q_v/A$ | 0,0409 | m/s |
| $Q_v$ (A=1 $mm^2$) | 4,09E-8 | $m^3/s$ |

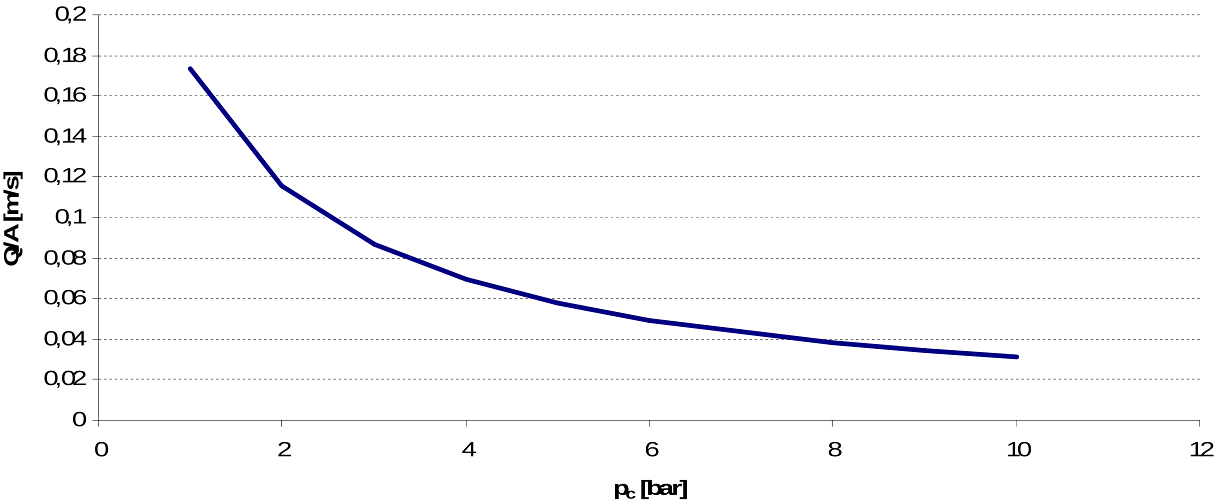


Fig. 4 Specific consumption for compressed-air (Tamb=60'C)

# 8 Conclusions

**[1].** A normal construction apparatus can be use in safe conditions in the Ex classified environment with an accessible effort to adapt it for the user.

**[2].** Acquisition efforts and compliance with requirements imposed by regulations on the use of technical apparatus in Ex classified locations are reduced.

**[3].** It shortens the time for putting in operation for objectives located in Ex environment, zone 2.

**[4].** Increases accessibility of economic operators to modern uncertified apparatus for use in Ex environment.

**[5].** There was identified a theoretical model to estimate the autonomy of "pz" pressurized equipment by method of loss compensation.

**[6].** A theoretical model was identified, to estimate compressed-air consumption in order to maintain overpressure and compensate the losses in pressurized equipments “$p_z$”.

**[7].** Numerical simulation revealed the favorable effect of using carbon dioxide over autonomy time value for pressurizations created by using protective gases from cylinders.

**[8].** Comparative study of the two solutions based on the use of the two pressurization sources: cylinder and compressed-air network showed the advantage of pressurization source that uses the compressed-air from the network.

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