Guide to Explosion Protection and Plant Safety

Explosion Protection and Plant Safety

In almost every industrial application flammable substances are used. Equipment installed in these areas needs to be explosion protected and must be approved and certified for this purpose. With suitable safety concepts, high availability and failure resistance, gas detection systems turn into reliable protection systems

Explosion Protection

In industrial processes very frequently flammable substances and sometimes also flammable dusts are involved. In these areas flammable gases and vapours may be released process-related (e.g. by relief valves) but also by unpredictable and hazardous incidents. Preventively these hazardous areas are declared to Ex-areas ("zones"), in which solely equipment may be installed which is equipped with a suitable type of explosion protection and certified accordingly.

Explosion protection is worldwide regulated. The basis of these standards according to IEC, CENELEC (Europe) and NEC 505 (North America) is very similar and is established on the "3-zones-concept", which is also more and more accepted in the USA,

Zone according to IEC, NEC 505 and CENELEC	Dangerous explosive atmospheres are present ...
Zone 0	continuously, long periods or frequently
Zone 1	occasionally, likely to occur
Zone 2	infrequently and for a short period only

while the well-known American way of explosion protection acc. to NEC 500 is based on the "2-divisions-concept":

Division acc. to NEC 500	Dangerous explosive atmospheres are ...
Division 1	likely to exist
Division 2	not likely to exist

According to IEC, NEC 505 and CENELEC there are seven standardized types of protection for electrical equipment in zone 1, while in North America (USA/Canada) there are only three types of explosion protection for division 1 according to NEC 500:

Type of protection acc. to IEC, NEC 505 and CENELEC	comparable type of protection acc. to NEC 500
Flameproof enclosure	Explosion proof
Encapsulation	–
Powder filling	–
Oil immersion	–
Pressurized apparatus	Purged / Pressurized
Increased safety	–
Intrinsic safety	Intrinsically safe

Nowadays powder filling and oil immersion are scarcely being used in the measurement and control technology and are not at all applied in gas detection. Pressurized apparatus, this means continuous purging e.g. with pressurized air, is a typical type of protection for major devices and cabinets.
The standardized marking of an explosion protected device, e.g. Ex de IIC T4 or Class I, Div1, Group B, C, D, informs the expert about the applicability in the designated hazardous area.

Type of Protection Intrinsic Safety

Products for measuring and control technology, which have relatively low power consumption, can be designed very smart in respect to their explosion protection. Smart, because the product is designed such that even in case of a first or second failure it is ensured that neither sparks of sufficient energy nor surfaces of sufficient temperature can occur – so no risk of ignition.

Electrical discharges must have a certain minimum energy **(ignition energy**), otherwise they will not be able to ignite the most flammable mixture of a given flammable gas with air – hence, certainly no other arbitrary mixture of this gas in air can be ignited.

Also, for a given gas, the surface temperatures of electric or electronic components shall not exceed a certain temperature **(ignition temperature**).

Therefore, if the electronic circuits of a product are designed accordingly and the stored electric energy (i.e. effective capacities and inductivities) as well as electrical power (i.e. electrical current and voltage) are limited to certain maximum values, this electronic circuit cannot act as an ignition source – the product is said to be intrinsically safe.

There is an important accessory for this: When intrinsically safe current circuits lead into the hazardous area they need to be protected against too high power by so-called **safety barriers**. Safety barriers at least contain a fuse, resistors for current limiting and Zener diodes for voltage limiting.

Intrinsically safe products are marked by an “i”.

Their design is sophisticated, lightweight and simple – and intrinsically safe products can be maintained while energized. Cables may be disconnected and sensors may be replaced without zone declassification – because sparks and hot surfaces surely cannot exist.

Type of Protection Flameproof Enclosure

The type of protection “flameproof enclosure“ is the oldest of all, having been used in the early mining industry since the beginning of last century (the marking “d“ refers to the German origin of this way of explosion protection). Compared to the protection type intrinsic safety a flameproof enclosure is a heavy and purely a mechanical method to avoid the ignition of an explosive atmosphere:

Simply let the explosion take place in the interior of the enclosure and reliably avoid a flashback. So housings of the protection type flameproof housing must be designed such that they will withstand the inner explosion pressure. The greater the housing’s volume, the higher is the possible explosion pressure, the more robust the housing shall be. If flammable gases penetrate into the interior of the housing, one can assume that the housed electronic circuits (which also may produce sparks or have hot surfaces) will ignite the gases. On ignition the enclosure will withstand the explosion pressure, and the explosion pressure is released via joints.
These mostly metallic joints with a certain minimum surface (with defined gap width and gap length) have an important function: Hot gases flowing along these joint paths are cooled down below their ignition temperature – a very effective flame extinguishing. With this type of standardized protection a potential flame in the enclosure’s interior cannot flash back into the hazardous area.
Flameproof housings are robust and heavy, and they are not allowed to be opened when energized. For maintenance an official hot work permission is necessary. The electrical connection of flameproof enclosed instruments can be made in three different ways:

1. **Rigid Conduit:** The electrical wires are run inside enclosed approved metal pipes. The pipes are directly screwed into the tapered NPT thread of the instrument.
The complete conduit system is specially sealed and flameproof.

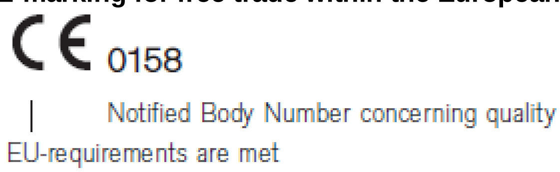
2. The cable is connected via an **approved flameproof cable gland**. Disadvantage: Explosion protection cannot be ensured by the manufacturer but only by the installer on-site.

3. The cable connection is done via an **approved junction box with increased safety (“e”).**

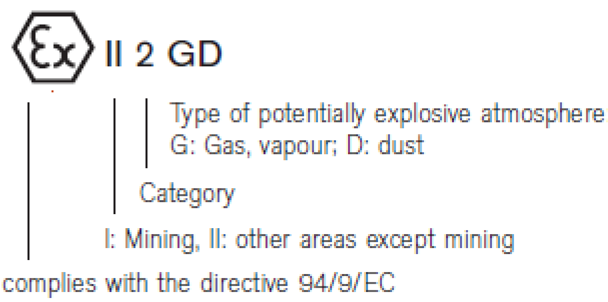
ATEX 95 – European Directive 94/9/EG

Also known as ATEX 95 (formerly ATEX 100a), mandatory in the European countries (EU) since 1st of July 2003, addressed to the manufacturers. Equipment and protective systems for the use in potentially explosive atmospheres need to fulfill the Essential Health and Safety Requirements (EHSR) which are assumed to be met when based on certain harmonized standards.

CE-marking for free trade within the European Union:



Marking (according to ATEX):



Explosion protection:

Ex ib IIC T4

- Temperature class
- Explosion group: I: Mining, II: other areas except mining for ia, ib, d and n: Subgroups IIA, IIB und IIC
- Type of protection (here: intrinsically safe)
- Explosion protected equipment

EC-Type Examination Certificate:

TPS 04 ATEX 1003X

- X: Special conditions
  U: incomplete Ex-component
- Number of certificate
- complies with the directive 94/9/EC
- Year of the certificate's publication
- Notified Body having type-approved the equipment

Device categories and safety requirements:

Device group	Category	Safety
I (Mining)	M1	very high
	M2	high
II (other areas except mining)	1	very high
	2	high
	3	normal

ATEX 137 - European Directive 1999/92/EG

Also known as ATEX 137 (formerly ATEX 118a), mandatory in the European countries (EU) since 30th of June 2006, addressed to employers and end-users concerning the minimum requirements for health and safety for workers in potentially explosive atmospheres.

Zone definition:

Gas, vapour	Dust	Explosive atmosphere
zone 0	zone 20	continuously, long periods or frequently
zone 1	zone 21	occasionally, likely to occur
zone 2	zone 22	infrequently and for a short period only

Selection of equipment (this table is the link between categories of the ATEX 95 and zones of the ATEX 137):

Operation allowed for	Gas, vapour (G)	Dust (D)
Devices of category 1	in zone 0, 1, 2	in zone 20, 21, 22
Devices of category 2	in zone 1, 2	in zone 21, 22
Devices of category 3	in zone 2	in zone 22

Example: In zone 21, where explosive atmospheres caused by dust are likely to occur, the instruments to be used need to have a marking **II 2D** or **II 1D**.

Necessary measures:
- Assessment of the risk of explosion
- Classification of the hazardous area into zones
- Marking of the hazardous places by means of a triangular warning sign “Ex”
- Adequate safety measures
- Explosion protection document
- Competence of employees
- Criteria for a permit-to-work system for dangerous work

Guideline for risk reduction:
- Prevent the formation of explosive atmospheres, or, if this is not possible:
- Avoid the ignition of the explosive atmosphere, or, if this is not possible:
- Minimize harmful effects of explosions to a tolerable degree.

Safety Integrity – SIL

The term Safety Integrity seems to be something like a fashion in the technical-based and automatically operated safety technology. But it is not, and fixed installed gas detection systems are not exempted from this trend to classify protection systems by means of the so-called Safety Integrity Level (SIL) in respect to their reliability to activate a risk-reducing safety action.

- Wherever there is a technical risk for people, assets or environment it is necessary to gain a certain degree of safety by means of risk reducing measures. If such measures are realized automatically by electric, electronic or programmable electronic systems the central term is “functional safety“.
- Such systems, frequently called protective systems or safety relevant systems perform a safety function and need to be adequately reliable in respect to the actual risk.
- However, such systems can fail by any arbitrary failure. If they fail they must not remain in a dangerous (unsafe) state and need to be repaired instantly. This however implies that the occurrence of a failure is detectable at all.
- A high fraction of all the possible failures (which are identified by a so-called FMEDA) can be made detectable by failure monitoring (diagnostic facilities), so that the system in case of a detectable failure can be forced into the safe state, which is said to react fail-safe.
- Statistically there is a very small remaining fraction of accidental dangerous failures which cannot be detected automatically, the so-called dangerous undetectable or DU-failure, which might be seldom, but will impede the execution of the safety function.
- Setting the probability of the occurrence of a DU-failure into relation to all possible failures this will result in the so called Diagnostic Coverage value DC and the important Safe Failure Fraction SFF. Both these values must exceed certain percentages depending on the individual safety requirements.
- By ingenious system concepts (especially by redundancies), periodically repeated function proof tests and preventive measures the probability of the occurrence of a DU-failure can additionally be decreased.
- The remaining residual risk can be assessed statistically and classified. This results in four different safety integrity levels SIL1 to SIL4, where SIL4 is reflecting the highest reliability but is not established for gas detection systems, which are rather SIL2 and – by means of redundancies – SIL3 rated.

Alarm Philosophy

What to do in case of an alarm? Gas detection systems are designated to trigger alarms in sufficient time to inform the operator about the alarm condition and to perform counter measures for the prevention of a dangerous situation. This is mostly an automatism, but can also be achieved by establishing an alarm plan. It is in the operator's responsibility to adequately react in case of an alarm.

The safety concept of a gas detection system always is:
Detect dangerous gas, **react** and **avert.**

Main alarm
The exceeding of only one alarm threshold (main alarm threshold) is basically sufficient. By this the safe state is achieved by protecting the hazardous area (visible / audible alarm and evacuation) or by shutting off gas supply or by disable the ignition sources, call for use of personal protection equipment or breathing protection etc. This is a safe but rigorous, so to say uneconomic measure – the entire process is affected and shut-down.

Pre-alarm
This can possibly be avoided by means of a pre-alarm which is activated at lower concentrations than the main alarm threshold. With the pre-alarm automatic counter measures can be initiated which, if they are effective, will prevent the main alarm from being triggered, e.g. a pre-alarm can activate an effective ventilation so that the gas concentration stops rising and the main alarm threshold is not exceeded. This is ideal because: **Via a pre-alarm a dangerous situation can be controlled without process shut-down.** It is the operator's interest to design counter measures so effective that the main alarm will most likely never be triggered:
Properly designed gas detection systems will reach main alarm only seldom or never.

Fault condition alarm
Fault condition alarms indicate that the system is partly or entirely inoperative and in case of a gas release cannot react properly. Preventively the same measures need to be taken in case of fault condition as in case of a main alarm, since there is no gas detection system at all. With this philosophy a safe condition is achieved best.

Sensor Positioning

A gas detection system's reliability is not only depending on the properties and performance of the equipment, but also depending on installation, operation and maintenance – and especially the proper positioning of sensors. Naturally, sensors can only detect a gas when the sensor is within the gas cloud. Incorrect sensor positioning results in a useless gas detection system.

Gas leaks can arise e.g. when cold liquefied and/or pressurized gases are released into the ambient air, and get mixed with it. Their concentration decreases, and the gas dispersion depends more on the current temperature conditions and ambient air convection than on the density of the pure gas.

Three Rules of Thumb:
- There are only three flammable gases which are considerably lighter than air: Hydrogen (H_2), Ammonia (NH_3), and Methane (CH_4). Commonly mixtures of these gases rise up.
- Vapours of flammable liquids are always heavier than air – they flow downwards as long as they are not disturbed by air convection.
- Independent of the density of the pure gas, gas concentrations of less than 1000 ppm in air virtually have the same density than air. Dispersion of concentrations like this will rather follow the current temperature profile and air convection.

Positioning strategy:
Having the sensors as close as possible placed at the potential leak surely is the optimum way. Leaks may arise from pumps, valves, flexible tubes and their connections, flanges, shut-off devices, bellows, etc. If such locations cannot easily be identified, sensors need to be distributed over the entire hazardous area (area monitoring). It is essential that the target gas always can reach the sensor at operational conditions within a given time interval. The local conditions of the individual hazardous areas are so very different that there are no regulatory standards where to place a sensor, but useful guidelines exist (e.g. the EN 50073 or IEC 60079-29-2).

Calibration

In a first approach gas sensors do not measure gas concentrations directly: Electrochemical sensors measure electron flow changes, catalytic bead sensors measure resistance changes, and IR-detectors measure changes of IR-radiation intensity in the near infrared. These changes always refer to the normal condition (clean air) which is called zero point because no target gas is present. Only by calibration it is possible to correlate a certain gas concentration to a certain output signal, resulting in a gas detection instrument.

Calibration is extremely important. Obviously, gas detection instruments cannot measure properly as long as they have not been calibrated properly. While zero-calibration is rather simple because ambient air can mostly be used for this purpose, calibration of the sensitivity (called span calibration) is not so trivial.
For the same reason that electrochemical sensors can detect reactive gases, they have to be calibrated using reactive gases. But unfortunately a lot of reactive gases also react with (moist) material surfaces and plastics.
Although from the aspect of safety it is recommended to perform the span-calibration with the target gas (the gas which shall be detected) there are several reasons to use an easy-to-handle surrogate test gas for cross-calibration.
If a variety of gases or vapours shall be detected by only one sensor, the instrument has to be calibrated for the substance the sensor is the least sensitive to. Thereby, the gas detector is calibrated to the safe side, because all gas concentrations are either measured properly or as too sensitive. The sensor’s sensitivity for certain gases cannot be calculated from gas specific data, but can only be determined by applying the gas and evaluate the response.
To achieve good measuring performance, calibration should be performed as good as possible under the expected conditions during operation.

Calibration chamber for flammable liquids

To obtain a given %LEL concentration of flammable vapours it is recommended to use a calibration chamber, where a certain calculable amount of liquid (e.g. 100 microlitres) has to be inserted. After complete evaporation a concentration of e.g. 50 %LEL is formed which can be directly applied to the sensor.

Requirements for Gas Detection Systems

Since gas detection instruments and systems are products of safety technology for industrial applications they need to comply not only with statutory requirements (e.g. electrical safety, explosion protection, electromagnetic compatibility) but also with further requirements such that even in harsh industrial environments the product's quality and reliability of alarming will sustain.

Standards concerning explosion protection:
Design requirements make sure, that devices will not act as a source of ignition. World-wide accepted standards are issued by e.g. CENELEC (ATEX), IEC, CSA, UL, GOST, etc.

Electromagnetic compatibility acc. to EN 50 270:
Test standards ensure that devices do not produce wire bound or radiated disturbances, and especially, that they are not negatively influenced by wire bound disturbances (surges, bursts) or high frequency emissions (80 MHz to 2 GHz at field strengths up to 30 V/m), and that they withstand electrical discharges without being affected in respect to their reliability. The relevant test standards are based on the series IEC 61000.

Climate, vibration and impact, e.g. acc. to IEC 60028:
Dry and damp heat temperature cycles (up to 70 °C, including condensation!) over several days and cold test. During these cycles, sporadic function tests and insulation resistance tests with high voltage are performed. Vibration test up to the 4-fold gravity for 90 minutes each axis at the determined resonance frequencies have to be passed without affecting proper function.

Measuring performance:
A certain measuring performance has to be met even under extreme environmental conditions (temperature, pressure, wind speed, relative humidity, vibration, etc):
EN 61 779 / EN 60079-29-1 – for flammable gases/vapours
EN 45 544 – for toxic gases and vapours

Digital communication acc. to EN 50 271:
Transmitter and controller nowadays are mostly microprocessor- controlled. Hardware and software need to comply with certain requirements concerning the system's reliability.

Shipping approvals:
Requirements of the so-called classification societies e.g. Det Norske Veritas (DNV), Lloyds Register of Shipping (LRS), Germanischer Lloyd (GL), Bureau Veritas (BV), etc.