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A New Approach to the Assessment of Explosion Risk of Dusts

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Quantitative/semi-quantitative explosion risk assessment methods are used for evaluation purposes [e.g. 2]. These methods are based on the estimation of explosion risk based on the frequency of occurrence of sources of ignition and possible effects of an explosion. The paper presents a novel approach to the assessment of explosion risk, which emphasizes process conditions (unit operations, construction and working conditions of equipment as well as the physical properties of the substances used). This enables the determination of the level of risks resulting from the process. Potential ignition sources are identified in the next step. These are then related to the estimated level of risk associated with the analysed unit processes. This is the final prerequisite for deciding whether or not to apply protection of the process units against effects of an explosion.

1. Introduction

The need to carry out an explosion risk assessment in production conditions at the risk of presence of flammable and explosive gases, dusts, mists, flammable vapours and fibres results from the provisions of the European directive Atex Users (Directive 1999/92/EC) on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (European Parliament and the Council, 1999). The assessment of explosion risks related to the possibility of explosive atmospheres occurring in workplaces should take into account at least (article 4, Directive 1999/92/EC):

a) the likelihood that explosive atmospheres will occur and their persistence,
b) the likelihood that ignition sources, including electrostatic discharges, will be present and become active,
c) the installations, substances used, processes, and their possible interactions,
d) the scale of the anticipated effects.

In the assessment of the risk of explosion on the basis of hazard identification, with risk estimation, the qualitative approach of is often used (Rogers R. L., 2000). The hazard assessment according to (Rogers R. L., 2000) uses Table 1 to assess the level of hazards arising from ignition sources, Table 2 to determine the possible effects of an explosion and the risk matrix to determine risk R (Table 3). This approach focuses on points (a), (b) and (d) above. The role of point (c), although obvious, is not directly taken into account. The adopted evaluation criteria (Tables 1 and 2) are of a qualitative nature. Thus, the estimated risk R (Table 3) is also of a qualitative nature.

Table 1: Category of the frequency of occurrence of effective ignition sources P which can cause an explosion.

Category (P)	Frequency of occurrence	Frequency of occurrence of effective ignition sources
5	Frequent	Occurs very often
4	Probable	May occur often
3	Occasional	Will occur several times during the period of use
2	Not likely	Unlikely but may occur during the period of use
1	Improbable	Highly unlikely, but possible

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Table 2: Determination of the consequences of incident S.

Category (S)	Effects scale identification	Effects description
4	Catastrophic	Fatal injuries or complete destruction of the system
3	Serious	Serious injuries or serious damage to the system
2	Minor	Minor injuries or minor damage to the system
1	Negligible	Insignificant injuries or negligible damage to the system

The "R" risk of incident results from the adopted P and S values, from Tables 1 and 2, and from the equation:

$$R = P \times S \quad (1)$$

where:
P - frequency of the incident (occurrence of an effective ignition source),
S - consequences that may occur due to an explosion.
Based on the determined R risk value and the risk matrix, Table 3, we estimate the level of risk acceptability.

Table 3: R risk matrix.

P \ S	4	3	2	1
5	A	A	A	C
4	A	A	B	C
3	A	B	B	D
2	A	B	C	D
1	B	C	C	D

This approach takes into account the following levels of risk:
A – unacceptable high risk, it is necessary to take proper technical, constructive (*) and organisational measures to reduce the risk;
B – high risk – necessary technical and organisational measures and consideration of the advisability of constructive measures;
C – medium risk – technical and organisational measures are recommended;
D – low (negligible) risk – measures intended to reduce the risk are not required.
* means appropriate protection measures against effects of the explosion (relief, suppression, isolation).

However, the identification of hazards with the estimation of the explosion risk R, based on the estimation of the scale/probability of the effects of the incident S and the frequency/probability of the occurrence of effective ignition sources P, may not lead to a correct evaluation of the situation, as it is largely based on a subjective assessment of what value of category P and category S should be assumed in a given process situation. This is not an easy task, and not only due to the subjective nature of the assessment. The R-value obtained leads to the classification of the risk in Table 3 to a certain level: unacceptable risk A, high risk B, medium risk C and negligible risk D. Such a defined level of risk leads to another arbitrary decision – what are the corrective actions (technical, constructive, organisational) that should be taken during the analysis.
In the course of risk assessment, the problem of interpretation usually arises, especially the problem of risk A. Specifically – what does risk A mean in a given procedural situation and on the basis of what criteria can we determine this level? If the risk is classified as level A, should a decision be made to stop the operation of the process? This is not an easy choice as it can lead to significant production losses. For this reason, risk acceptance decisions at level A should be based on clear conditions, and those should follow the identified risks and omissions in terms of ensuring explosive safety. One may have problem with high risk B too. Does it always require constructive and technical measures to be taken? Is it not enough to apply only technical measures and consider the need for constructive measures? What criteria should we use to decide this?
The explosion risk assessment carried out using the procedure for determining the R risk value, shall also take into account the possible effect of an explosion S (Table 2). The estimation of the value of S is based on a descriptive definition of the scale of possible effects of an incident (catastrophic, severe, minor, negligible) and on the characteristics of the possible effects (fatalities..., minor injuries..., insignificant injuries...). Sometimes the assessment of S is also based on an estimation of the scale of possible financial losses. Both approaches have similar drawbacks – the need for arbitrary decisions without justified reasons. How and on the basis of what criteria can we predict when the catastrophic consequences will be assumed? And what does it mean?

2. Effects of process factors on the assessment of explosion risks

The presented typical methodology of explosion risk assessment introduces a vague concept of the frequency of occurrence of a potential ignition source (Rogers R. L., 2000) which is difficult to quantify. Undoubtedly, the frequency of the occurrence of sources of ignition is very important. But is this the only hazard to be taken into account? And how to relate the definition of the frequency of ignition sources (Table 1: occurs very often, …, but may occur during the period of use) to the real process situations that we encounter in the industry? In practice, the flammable and explosive properties of processed substances should also be taken into account. In particular, the value of the minimum ignition energy MIE. The higher the MIE value, the shorter the list of potential ignition sources. For example, for hard coal dusts, for which the MIE > 1000 (7000) mJ, the risk from typical spark and brush electrostatic discharges is usually not taken into account. But the situation is very different in case of lignite dusts (much smaller MIE value). Other important factors that should be taken into account are the type of unit operation (continuous, batch), type and construction of the device and its working volume. For example, it is known that in the case of slender devices (silos, bucket elevators), the ignition risk due to friction and static charging of falling particles leads to the accumulation of static electricity on their surface. But even if we determine which ignition sources may be present (e.g. surface temperature too high), how can we reliably determine the frequency with which this potentially effective ignition source occurs? Too high a surface temperature may be caused by the process conditions and the frequency may be evaluated in that case. However, too high a surface temperature is also possible and (particularly dangerous) in a failure situation, e.g. a bearing seizure. But how can we estimate how often this incident can occur?
The type of unit operations carried out and the type of the material flow are also important. For example, mechanical transport (excluding bucket elevators) provides conditions for a laminar flow. On the other hand, a number of operations take place in devices in which, due to their design and principle of operation, turbulent flow of material occur. This includes bucket elevators, filters, tanks. The turbulent movement of materials, often necessary for process reasons, increases hazards and risk. In many situations, process hazards that can cause a real ignition hazard can be identified and thus an attempt can be made to reduce them. But proposing appropriate changes in technology, process conditions or the design of some devices is no longer so easy may even be impossible. Despite the obvious benefits – reduction of hazards – i.e. improvement of workplace safety. Consequently, in such situations, it is necessary to decide on the use of constructive measures (relief, suppression, isolation) to protect the process equipment and process nodes against the effects of an explosion. Only this solution allows to become fundamentally independent of the threats and problems mentioned above.

3. Safe working volume of the process equipment

The concept of "safe" working volume is important from the point of view of explosion safety, but it is very difficult to define. Because is the working volume of the device 1 m^3 already dangerous and lead to serious consequences in case of an explosion or not? Industrial practice and knowledge do not provide a good answer here. So, from what operating volume should the real threat to the system, staff and the environment due to ignition and explosion be taken into account? European standards and directives do not provide any assistance here. Only the NFPA 652 standard (NFPA 652, 2016) recommends protecting the process equipment starting from a working volume of 0.2 m^3, determining that under these conditions deflagration combustion (combustion spreading at subsonic speeds) can lead to serious hazards.
But does this mean that even with such small volumes, it is possible and necessary to protect the equipment from the effects of an explosion? Industrial experience in protecting process equipment and process nodes against explosion has shown that the working volume of protected equipment should be higher. And it will depend on a number of process factors discussed earlier. This is related, for example, to the slenderness of a device. Unit with a similar height value of L to diameter D (slenderness L/D = approximately 1 to 2) are relatively easy to protect against the effects of an explosion. The hazards increase together with the L/D ratio and, of course, the working volume. Estimates resulting from industrial practice, related to the protection of process equipment against explosion effects, and which take into account the associated costs, recommend the protection of equipment with an operating volume of at least 4-5 m^3.

4. Risks due to explosion propagation in process equipment

If a typical explosion risk assessment procedure e.g. (Rogers R. L., 2000) is used the analysis of possible process hazards and the resulting consequences is generally not carried out in details. This approach does not take into account, apart from potential sources of ignition, a number of process factors discussed earlier. Therefore the explosion risk assessment procedure should take into account the properties of the dust (minimum ignition energy), the nature of the movement of the bulk material and the dust content (turbulent/laminar), the design of the device (slenderness, working volume) or the type of individual operation (continuous/batch operation). Such process based approach would allow for a much more accurate assessment of the situation. It is known from industrial practice that, due to their construction, the nature of dust movement and the conditions under which they are carried out, process equipment with a high risk of explosion and ignition include silos/tanks (storage), filters (dust extraction), bucket elevators (mechanical transport), mills (grinding) and dryers (drying). It can be estimated that over 50 % of explosions in the industry have their origin in these types of devices. In addition, the industrial practice has shown that, in the event of an explosion, particularly dangerous consequences are related to the possible propagation of pressure and flame via the process piping connecting the process equipment. The damages and the financial consequences of this can be very serious. Limiting the explosion to the origination device is therefore essential to ensure explosion safety. Today, the industry has the appropriate techniques for isolating explosion in order to eliminate the risk of explosion propagation in the plant.However, the legal situation resulting from the provisions of Directive 1999/92/EC, Annex II point 2.5 is not clear enough: all necessary measures must be taken to ensure that workplace, work equipment and associated connecting device ... as to minimize the risks of an explosion and, if explosion does occur, to control or to minimize its propagation within that workplace and/or work equipment. Does this clearly mean that the risk of explosion propagation must be eliminated? In what situations should a decision be taken whether or not to take measures against the propagation of an explosion? And who should do it, and on the basis of what criteria?

After all, such a decision may have not only serious financial but also legal consequences. This major and important challenge is not being sufficiently addressed by the industry. Estimation of the risk resulting from the explosion propagation hazard in process equipment to adjoining equipment in the process line and possible consequences is yet another challenge for science, technology and law.

5. Alternative approach to explosion risk assessment

The analysis outlined above raises the important question of what characteristics should an explosion risk assessment have in order to become a tool that will take into account the relevant technical and process factors, and not only potential sources of ignition? Should it be a tool for making technical or even financial decisions? The explosion risk assessment should, according to Directive 1999/92/EC of 16 December 1999 take into account the device and installations in operation, used substances, their mixtures, processes taking place and their interactions. Thus, the factors discussed earlier and considered important, but not only ignition sources. The proposed approach to explosion risk assessment would require the development of a publicly available and reliable database of recorded explosions, their causes and consequences. This database should be systematically supplemented. However, this would require the cooperation of the relevant technical services of the EU countries. It would probably require the implementation of a new directive forcing the collection, description and sharing of full information on such incidents, at least for those industries in which an explosive incident has occurred. Although the BIA report (Beck et al., 1997), which contains a summary of explosions with a brief description of their causes and effects, is available, it concludes on cases from 1997.

Also, the reports contained therein do not describe explosion incidents at the level of detail required by the explosion risk assessment. The database of recorded explosions would provide a reliable statistical knowledge base on explosive hazards associated with typical individual operations created over the course of a decade. This is illustrated by the data in Table 4. Granted, the data contained therein concerning the percentage of explosion hazards caused by a specific individual operation (device) are not based on an available database, they are solely based on general knowledge and experience. The summary shows that explosions are primarily related to the storage and dust extraction processes, followed by milling, mechanical transport and drying. Similar draw a conclusion may be found in Yuan et at. (2015).

It will not be an easy task to persuade the EU community to make efforts to set up such a database. This is clear, but the benefits for future production safety would be unquestionable: better assessment of possible risks leading to greater “reliability” of risk assessment and thus better protection of human health and life, the environment and workplaces. There are also the invaluable training advantages resulting from access to this type of database. Persons and services responsible for the safety of industrial plants have a right to expect this. If so, the assessment of the explosion risk of an industrial installation should focus, to a large extent, on this type of individual operation. In these cases, in particular, the possible risks arising not only from potential ignition sources but also from the design of the device, its operation, working volume, flow characteristics and physical properties must be taken into account. It follows from the above that the proposed risk assessment will require sufficient knowledge of the process. The proposal to adopt boundary values for the analysed process risk factors is summarised in Table 5. The assumed levels of values for particular risk factors were coupled with 4 levels of hazard (very high, high, moderate, low). The approach assumes that in the first phase of the assessment, the risk factors will be analysed and assigned the hazard levels contained in Table 5. These values are, in fact, arbitrary, but are based on the authors' knowledge and experience.

Table 4: Percentages of typical individual operations as a potential explosion hazard location.

Process / device	Percentage [%] (estimates)
storage (silos, tanks)	20
dust extraction (filters, cyclones)	17
milling (mills)	13
mechanical transport (bucket elevators)	10
drying (dryers)	8
afterburning systems	5
mixing (mixers)	5
polishing and grinding	5
screening (sieves)	3
Other	14

Table 5: Risk factors to be taken into account in the proposed approach for explosion risk assessment. For dusts.

Hazard levels / Risk factors	Very high	High	Moderate	Low
Minimum ignition energy MIE, mJ	MIE ≤ 30	30 < MIE < 100	100≤ MIE < 500	MIE≥ 500
Device slenderness S	S > 5	4 < S ≤ 5	3 < S ≤ 4	S ≤ 3
Device $V_{\mathbf{rob}}$ (m^3)	V > 15	10 < V ≤ 15	5 < V ≤ 10	V ≤ 5
Device operating mode	batch (1)	batch (2)	continuous (3)	continuous (4)
Material flow	turbulent	transitional	laminar	laminar
Lower explosive limit LEL, g/m^3	LEL ≤ 30	30 < LEL < 60	60 ≤ LEL < 120	LEL ≥ 120

where:
(1) frequent stops at the production node due to e.g. a change in raw material (estimated once per shift)
(2) process stoppage is temporary (estimated once a week)
(3) continuous operation of the device
(4) continuous operation of the device, presence of a dust cloud in normal conditions is not expected.

The order of risk factors adopted in Table 5 is not accidental. It is justified by the knowledge resulting from the implementation of projects related to ensuring explosion safety for production plants. The value of the minimum ignition energy MIE and the slenderness of the device S as well its working volume V are the key factors. Assigning the values of the analysed process parameters (risk factors) to a specific level of hazard will also allow more effective identification of possible ignition sources in a given process situation (EN 1127-1: 2007). The four hazard levels adopted in Table 5 are arbitrary. The number of hazard levels can be extended. However, this should be due to the complexity of the analysed process. Table 5 refers to the individual operations identified as particularly relevant in Table 4: storage, dust extraction, milling, mechanical transport, drying. If it is necessary to analyse more than one individual operation, the assumed order of priority of the risk factors and the assumed values of threat levels may be different. At this stage of the analysis, the principle was adopted, based on the data contained in Table 5, and considered sufficient to make a preliminary decision on the necessity of protecting the analysed process node against explosion effects, when the values were: MIE ≤ 30 mJ, S > 5, Vrob > 10 m^3 and we take into account batch operation (**) of the given process node. The proposed protection system against the effects of explosion should cover both the protection of the process equipment and its feeding and discharge points. Making a final decision would require a detailed analysis of the possible sources of ignition (EN 1127-1: 2007) especially where the MIE value of the material present in the process is relatively high.

Knowledge of the process and practical experience in explosion protection techniques are therefore essential. Knowledge of the law and the available standards is also important. This is due to a number of technical constraints related to the possibility of applying specific explosion protection techniques in process devices. These restrictions are related, among other factors, to the location of the device (hall / open space, location in relation to other devices/structures). The final decision belongs however to the employer who ultimately takes responsibility for it (Directive 1999/92/EC). Furthermore, it must be based not only on the knowledge resulting from the assessment of the production installation but also on necessary expenditures related to ensuring the explosion safety of the production installation (purchase, installation and commissioning of a given protection system). This often becomes a deciding factor for the adopted technical and protective measures.

6. Process node analysis – dedusting

The dust is extracted from the process using a typical filter design (filter cartridges). The dust extraction is carried out continuously and takes place under conditions of turbulent movement of a stream of dusty air into the dust extraction chamber. The values of dust parameters and filter design adopted for the analysis are as follows: MIE <30 mJ, LEL<60 g/m^3, slenderness S< 3, working volume V< 15 m^3. This means that the risk is very high (MIE, turbulent flow), high (V, LEL) and low (S). Therefore, these are not unequivocal reasons to reach a decision to protect the node from the effects of an explosion. An analysis of possible sources of ignition will be an additional criterion. In the operating conditions of the filter the risks caused by static electricity (impact of particles against each other and the walls of the filter) associated with friction leading to an increase in temperature (turbulence and impact of particles), mechanical sparking (possible contamination of the raw material) and hot particles (when the filter is connected e.g. with a milling process) must be taken into account. In those cases, when mechanical sparks and hot particles can be eliminated, in practice the risks of friction and static electricity still remain. These cannot be effectively eliminated within the space of the dust extraction chamber. The risk related to friction (leading to an increase in temperature) is low, as the impact of small particles will not generate high energy. However, the hazard resulting from the risk of static electricity, due to the low MIE value of the dust, will determine that a decision should be taken to protect the filter from the effects of an explosion. This will include both the filter itself and the risk of an explosion in the filter propagating through the dusty air duct to the process system and the discharge system of the filter (usually into a container where dust is collected).The protection of the filter itself (by explosion relief or suppression) is a separate issue that must be analysed on a case-by-case basis. The application of explosion relief, which comes to mind due to relatively low costs, is often not possible due to the filter location and surroundings. Alternatively, an explosion suppression system (based on HRD cylinders with suppressing powder) can be used to circumvent these limitations. The process system is protected against explosion propagation (pressure and flame spreading from the working chamber of the filter) to the dusty air duct and dust discharge system by means of explosion isolation.

7. Conclusions

The proposed explosion risk assessment of dusts takes into account the following main process risk factors: minimum ignition energy of dust MIE, slenderness and working volume of the process unit, continuous or batch operation, turbulent/laminar transport of materials, lower explosion limit LEL and a good knowledge of the process. The approach provides the limit values of analysed risk factors in relation to the assumed hazard levels (Table 5). The significance of the proposed risk factors was shown for an analysed dust extraction node. The determination of the ignition and explosion hazard R associated with considered operation should be estimated on the basis of the risk factors adopted in Table 5 and the hazard levels assigned to them. The methodology for the determination of R values is currently under development. Among other, it is intended to answer two questions: should the process device/node be protected against explosion and can the risk be reduced to an acceptable level, especially in moderate risk conditions, solely by ensuring process safety?

References

Beck H., Glienke N., Möhlmann C., 1997, BIA-Report, Combustion and explosion characteristics of dusts,13/97, HVBG, Sankt Augustin, Germany.

Directive 1999/92/EC of 16 December 1999, Atex Users.

EN 1127-1: 2007, Explosive atmospheres - Explosion prevention and protection - Part 1.

NFPA 652 Standard on the Fundamentals of Combustible Dust, Edition 2016.

Rogers R. L., 2000, The RASE Project “Explosive Atmosphere: Risk Assessment of Unit Operations and Equipment”, EU Project No: SMT4-CT97-2169.

Yuan Z.Z., Khakzad N., Khan F., Amyotte P., 2015, Dust explosions: a threat to the process industries, Process Safety and Environmental Protection, 98, 57-71.