

The "Duktus" for the Assessment of Explosion Hazards – A Methodical Toolbox for Application

Katharina Maiwald, M.Sc.Eng.; Bastian Liske, M.Sc.Eng.; Prof. Dr.-Ing. Uli Barth

University of Wuppertal, School of Mechanical Engineering and Safety Engineering, Chair of Methods of Safety Engineering and Incident Research, Germany

To avoid explosions in powder, fluid or gas handling processes it is necessary to identify, analyse and evaluate current or potential explosive hazards. Explosive hazards have to be validated according to the directive 1999/92/EC, also known as ATEX. These international requirements were implemented in the German technical rule for operational safety TRBS 2152 where the so called „Schacke-Müller'sche Duktus" (short: Duktus) is used as a method to assess explosive hazards.

The Duktus follows a proven and accepted approach. It provides a yes/no-questionnaire regarding the order of priority which is determined by legal requirements. Based on the evaluation of the atmosphere/mixtures inside an apparatus but also in the surrounding and the effectivity of current ignition sources, certain measures could become necessary. After prevention of the formation of explosive atmosphere and avoidance of the ignition of present explosive atmospheres, explosion protection by design has to be installed to protect health, safety and the environment.

A lot of risk evaluation methods for plant and process safety exist and they require experience, training or expert groups to be applied correctly. Responding to the Duktus questionnaire could also be a problem for inexperienced people. This contribution therefore aims to provide a helpful methodical toolbox to support the application of the Duktus.

Introduction

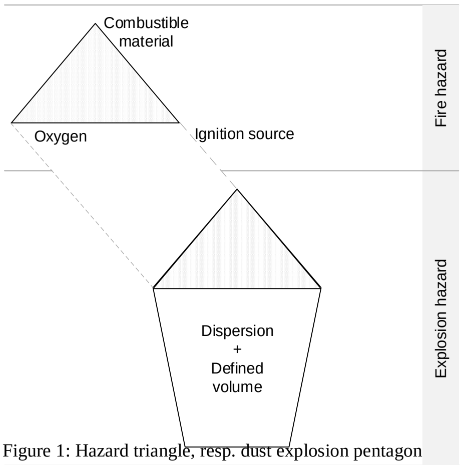

Figure 1: Hazard triangle, resp. dust explosion pentagon

If the conditions for a fire or an explosion - described by the so called hazard triangle or the dust explosion pentagon (figure 1) - are present and fires and even explosions with devastating effects cannot be excluded, primary, secondary or tertiary measures has to be implemented, cf. (Barton 2002). Explosions should not occur by dismantle the dust explosion pentagon on one side by means of preventive measures, although the hazard might be further present, cf. (Cloney et al. 2014). Because of engineering requirements and needs or qualitative product standards the avoidance of a potential explosive atmosphere, respective mixture[1] (GefStoffV), by means of primary measures like replacement of the combustible material are rare to apply. In addition, the avoidance of potential ignition sources by secondary measures, which belongs also to preventive measures are hardly to exclude because of manipulations and the knowledge about the possibilities that so called black swans (Taleb 2010) including the events of unknown unknowns (Daase und Kessler 2007) could take place. The principles of integrated explosion safety indicates a higher priority on enhancing prevention over protection. This requires stable and in particular controllable conditions. But modern technologies and the more and more increasing complexity of hardware and process conditions complicates these evaluation.

To find out the most effective measures assessing explosion hazards are a necessity for working equipment and facilities within the operational assessing. In addition, risk evaluations regarding to getting a CE-type conformity or the assessment of hazards by the implementation of audits or the documentation of loss prevention reports could be required, too (Lottermann 2012). To take up the challenge of an evaluation of explosion hazards the so called „Schacke-Müller'sche Duktus" (short: Duktus) is used as a method to assess explosion hazards. The Duktus follows a national proven and accepted approach with functional practicability. It provides a monocausal yes/no-questionnaire (see figure 2) regarding to the order of priority, which is determined by legal requirements (EU Parlament 1999). First of all the user has to know the safety characteristics of the handling product. The formation of hazardous explosive atmosphere has to be estimated in combination with the dispersion of the product and the predefined volume. Measures should be implemented, if this cannot be excluded. This leads in the zoning of the areas with hazardous explosive atmospheres regarding to the frequency of their existence. Measures to avoid ignition sources are the consequence. If the ignition of the hazardous explosive atmosphere is not reliable prevented, technical explosion safety measures in order to limit the detrimental effects of an explosion to ensure health and safety should take place (Lottermann und Barth 2008).

[1] An explosive mixture is a mixture out of flammable gases, vapours, mists or dispersed dust and air or other oxidising agents, which reacts in a self - propagating flame spread after the ignition source becomes effective, which in general leads to a temperature and pressure escalation. Hazardous explosive atmosphere is a hazardous explosive mixture with air as oxidising agent under atmospheric conditions (ambient temperature of -20 °C to 60 °C and pressure of 0,8 bar to 1,1 bar). Thus the explosive atmosphere is a subset of the explosive mixtures.

This questionnaire handout according to the technical rule (TRBS 2152) cannot guarantee a successful assessment of hazards without experience regarding to the assessing of the plant and their products. Due to the variety of hazardous explosive atmospheres by fluids, dusts or hybrid mixtures as well as the huge number of different potential effective ignition sources and the complexity of the identification of both - hazardous explosive atmosphere and ignition sources as well as their prevalent interaction - difficulties in the application does still exist (Miranda et al. 2015). The simplified manner of the Duktus needs also experienced persons, but the methodology themselves in combination with the contributed toolbox allows a systematic and self-explanatory way.

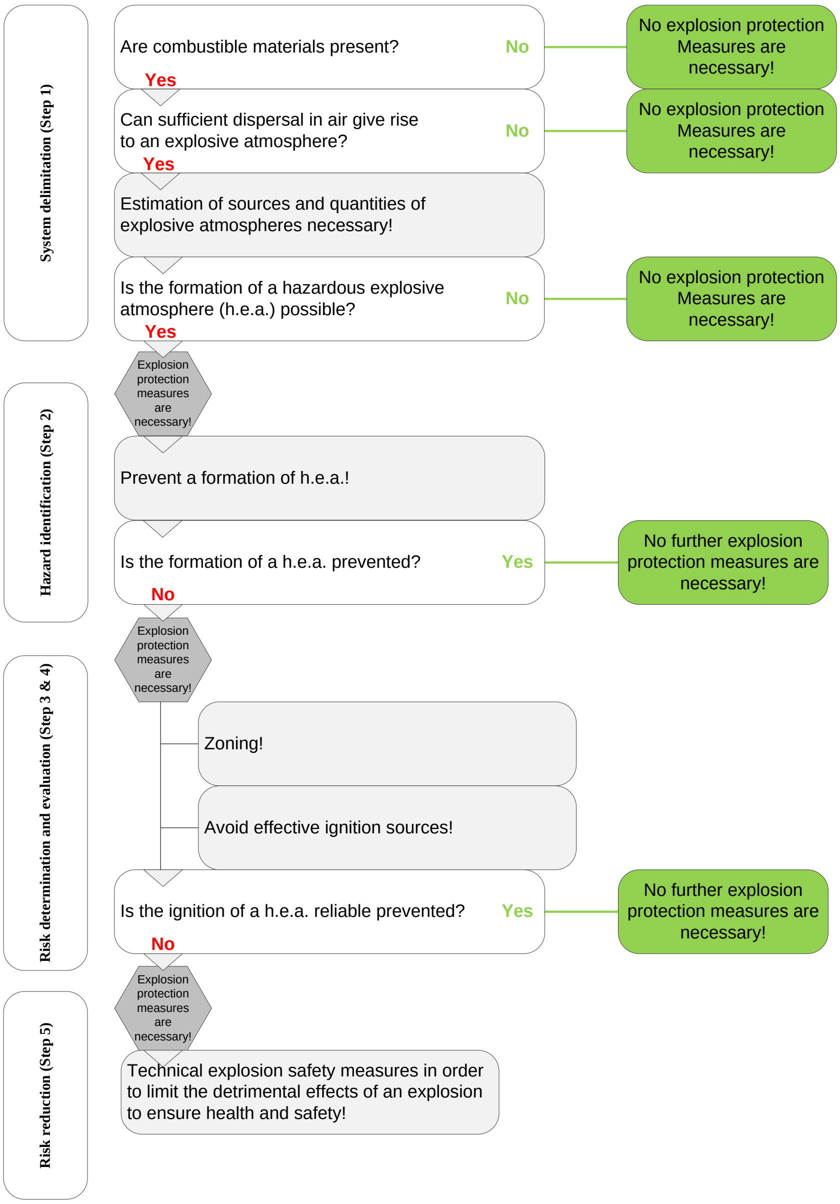

Figure 2: Questionnaire of the Duktus, according to the TRBS 2152 (TRBS 2152; Lottermann und Barth 2008)

Legal Basis

The legislative framework of the European Union presents minimum rules within the so called New-Legislative-Framework (NLF) to improve the working environment, among which are also two directives correlated to the explosion protection. On closer examination the first directive deals with the internal explosion prevention (directive 1999/92/EC) and the second concerns equipment and protective systems for use in potentially explosive atmospheres (directive 94/9/EC till 20.04.2016 and directive 2014/34/EC as from 20.04.2016). The directive 2014/34/EC is not yet transferred to the German law. The special characteristic consists in the fact, that these directives are not only valid in the European Union, in context of the elimination of trade barriers and due to alignment to the laws of the most important trading partners these are also valid in the Swiss confederation.

The implementations of the European directives can be found in the Hazardous Substances Ordinance (Gefahrstoffverordnung) and in the Ordinance on Industrial Safety and Health (Betriebssicherheitsverordnung) concerning directive 1999/92/EC and in the 11. Product-Safety-Regulation (11. Produktsicherheits-verordnung) for directive 94/9/EC. Clarifications and specifications the ordinance undergo by the technical rules and by regulations of the accident insurance institutions for the industrial explosion protection or by harmonized standards for the scope of equipment and product safety. In both states these not only concrete the legal norms, but they also serve the state of the art and allow the user to suspect, that he corresponds to the legally required rules in safety and prevention while practicing according to them.

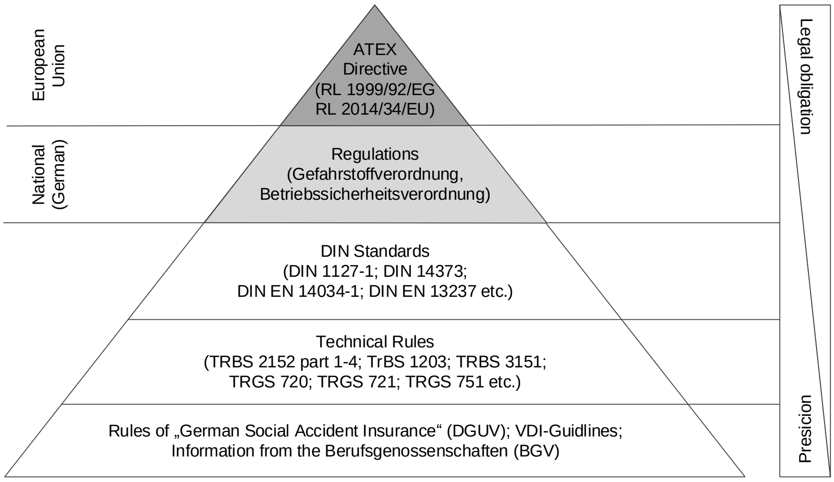

Figure 3: Exemplary pyramid of German legislations

The legal obligation decreases from top to bottom, whereas the precision increases.

Methodical Toolbox

As follows the described scheme based usually on tabular tools and is partly used in the examples of the VDI guidelines (VDI-Richtlinie 2263 - 7.1). But nevertheless, analysis methods like the well-known and accepted Hazard and Operability analysis is partly integrated. The toolbox also helps to use these methods, but requires a general knowledge of these procedures. That means that certain competences – which describes the expertise and competence - were provided for the assessment of explosion hazards. Encompassing it is described in the competence-model of (Lehmann und Nieke) by the terminology of professional-, methodology-, social- and self-competence. In terms to the implementation of the Duktus as a methodical toolbox the content-related professional as well as the methodical strategically knowledge is emphasized, while social competence and confidence is provided at the same way. The professional competence includes the knowledge, the understanding of the plant and their processes as well as the ability of the recognition and the reflection of technical failures as an example. The user should be able to ask appropriate questions within the meaning of hazard identification and evaluation and has to know where to find the answers, e.g. with help of the research of legal requirements. Besides this, the methodical competence describes the structured work in combination with organisation and planning which requires the knowledge about existing methodical possibilities in the context of risk, respective hazard evaluation. These competences are forming the amount of single competences regarding to action and decision-making and enable the assessing person not only to the realisation of tasks but also honours someone as an expert in this field.
The risk evaluation – as the total procedure of risk identification, risk analysis and risk assessment – and the following risk reduction (DIN ISO 31000:2009) is an accepted and normative procedure to evaluate all possible scenarios of risks. These named steps can be transferred directly to the explosion protection and the assessment according to the steps of the Duktus. Firstly, it is necessary to define a general accepted limit of risk. Per classical definition risk can be calculated as a multiplying product of the factors probability (P_{Ex}) and damages and the severity (S) of them.

$$Risk\ (R_{Ex}) = f(S, P_{Ex}) \tag{1}$$

In case of an explosion a not accepted damage severity is expected and the probability is basically characterized by the probability of the occurrence of an explosive atmosphere and the likelihood of the presence of effective ignition sources. This context is expressed in equation (2).

$$Risk\ (R_{Ex}) \approx P_{Ex} = P_{atmosphere} \cdot \sum P_{ignition\ source} \tag{2}$$

According to the probabilistic application the damage severity used as a constant, caused by assuming a worst case scenario, while the probability of occurrence is equal to the zoning in dependence on the presence of ignition sources. It is necessary, that the predefined and calculated risk has to be lower than the critical limit of risk at all.

$$Risk\ (R_{Ex}) < critical\ Risk\ (R_{Limit}) \tag{3}$$

The risk identification as a process of finding, recognition and description of risks is equal to the characterisation of the material in combination with the process-related surrounding conditions and the possibility of the formation of hazardous explosive atmospheres. The risk assessment and the accompanying determination of the tolerated risk is answered with each final question before risk reduction by implementing measures. With help of this risk reduction one side of the dust explosion pentagon should be surely eliminated. Otherwise explosion protection by design measures should reduce the effects of explosions to a harmless or tolerable level, cf. (Lottermann 2012).

Practical Application Example

In the following described steps (step 1 to step 5), the method in principle and the theory should be in focus to present a methodical toolbox - which can apply for different types of plants, processes and substances - in general. The practical application for the example of a spray drying process is primary shown within the figures 5-7, which represented simultaneously the described toolbox. The application example is grey shaded and should allow a better understanding of the contributed methodical concept without any claim to comprehensiveness. A detailed process description is omitted.

The total system of a spray dryer is divided into the subsystems depicted in figure 4. To simplify this complex example of a plant, the subsystem of the drying chamber is used for the application procedure in each of the following assessment step.

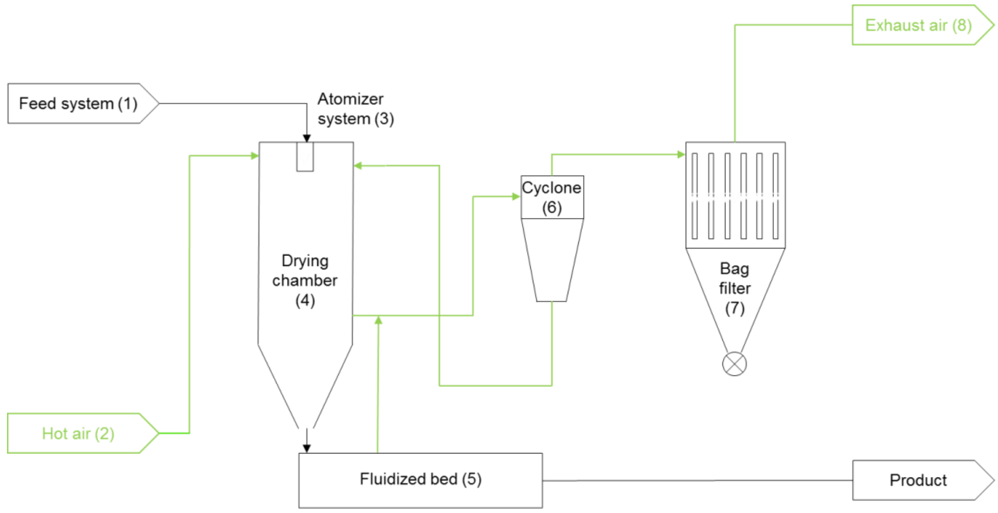

Figure 4: Spray drying plant

Transparency of Adequate Equipment and Process Conditions (Step 1)

The creation of transparency in the understanding of the plant, their process and the handling product forms a preceding operational step of the Duktus (figure 2), because with insufficient knowledge of these equipment and process conditions, a facility related, integrated and realistic assessment of fire and explosion hazards is impossible. The selection of a suitable employee for the assignment of the task is evident.

At the beginning of an evaluation the definition of the limits and the intended use of the machinery shall be made. The segmenting of the plant as the overall system in their subsystems could be necessary (=system delamination), because otherwise the facility and their differences in conditions becomes more and more complex. To have a valid basis of equipment and process conditions the user should have an insight in several documents. A first overview should give minimum information about the volume and material of the predefined subsystems as well as pressure related resistance and the mass balance. Regarding to the product all necessary safety characteristics should be determined under laboratory conditions by an independent institute. Hereby it is to differ between deposited and dispersed dust as well as characteristics for fluids, respective gaseous state of aggregations.

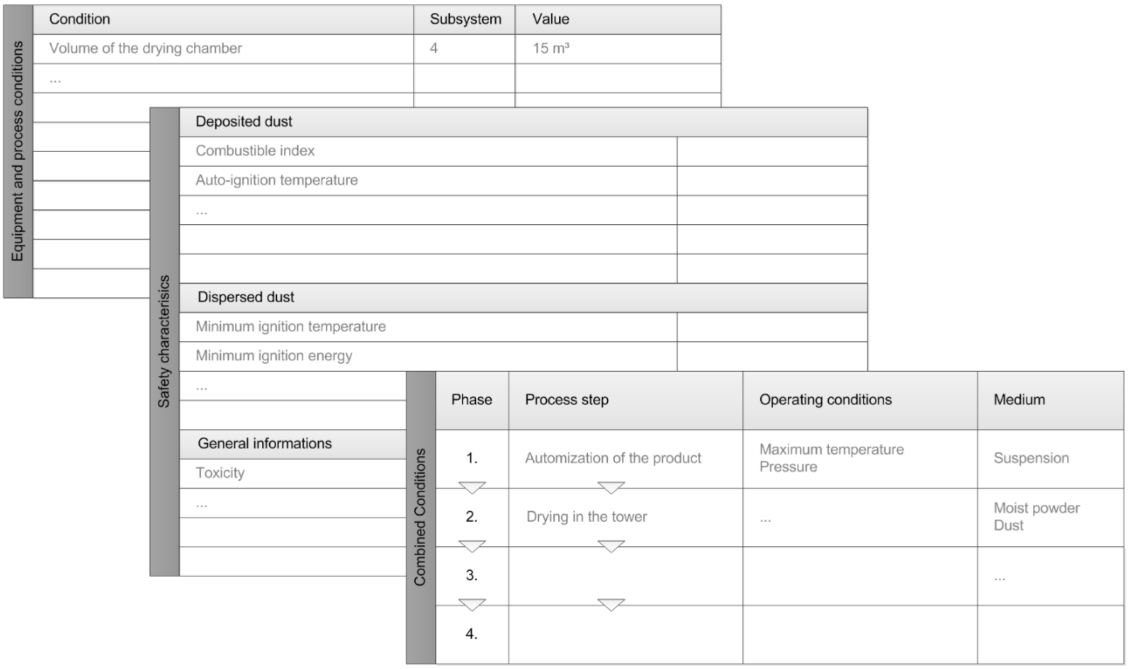

Figure 5: Tabular toolbox for step 1, Transparency of adequate equipment and process conditions

Formation of Hazardous Explosive Atmosphere (Step 2 and 3)

With help of the previous collected information the first questions by following of the Duktus can be answered. The evaluation about the potential formation of a hazardous explosive atmosphere is equal to the step of the risk identification. For a systematic evaluation the tabular toolbox of figure 5 is used for each phase of the process which was defined in *step 1* and in dependence of each predefined subsystem.

The presence of a combustible material is usually known from the history, experiences or the state of the art and documented lists like the BIA report (Beck et al. 1997). Otherwise the combustible index as an accepted safety characteristic helps to characterize the burning behavior. So far combustible material is present in dangerous quantity in the process and a dispersion, whether accidentally or due to normal operations in the production process themselves, the building of an explosive atmosphere cannot be excluded. The assessment of sources and quantities, for example with help of the heat and mass balance, provide information about the presence of hazardous explosive atmosphere, which requires further measures to maintain health and safety (GefStoffV). The amount of the so called dangerous quantity should not to be underestimated, because the smallest amounts are able to form hazardous explosive atmospheres in a certain volume. Some experience can give quantity values. Generally more than 10 litres coherent explosive atmosphere in a closed room independent of the room size needs to be considered as hazardous explosive atmosphere. In rooms < 100 m³ less than 10 litres could be dangerous. In the case of combustible dusts, even a plain dust deposit of 1 mm over the whole ground space is enough to fill a room with an explosive dust-air mixture after dispersing, cf. (TRBS 2152 Teil 1).

The HAZOP analysis (HAZard and OPerability analysis) is used for the investigation of technical disturbances, which can also lead to the composition of an explosive atmosphere. On this occasion each predefined subsystem must be considered, too. By applying of HAZOP deviations from normal conditions of a process, due to disturbances or failures as well as their causes and effects can be detected, cf. (Preiss 2009). For this purpose, the guide words (no or not, more, less etc.) depicted in figure 5 are used to express a certain type of deviation of an element from its normal function. The HAZOP analysis is, due to its international anchoring (DIN Norm 61882) of the directive, an acknowledged and well known procedure, especially in the chemical process industries. It is also conveyed through various courses.

Furthermore, human factors can also cause deviations from normal operation. They need to be integrated under any circumstances. Inadvertently manipulations due to carelessness and lack of science are often the cause of unexpected incidents. For example, carelessness, such as the incorrect implementation of measures (e.g. cleaning with a broom instead of an explosive protected vacuum cleaner), or lack of training and regular instructions, may cause the formation of a hazardous explosive atmosphere. All these conditions must be considered and entered in the tabular overview in order to show that all eventualities were taken into account in the assessment.

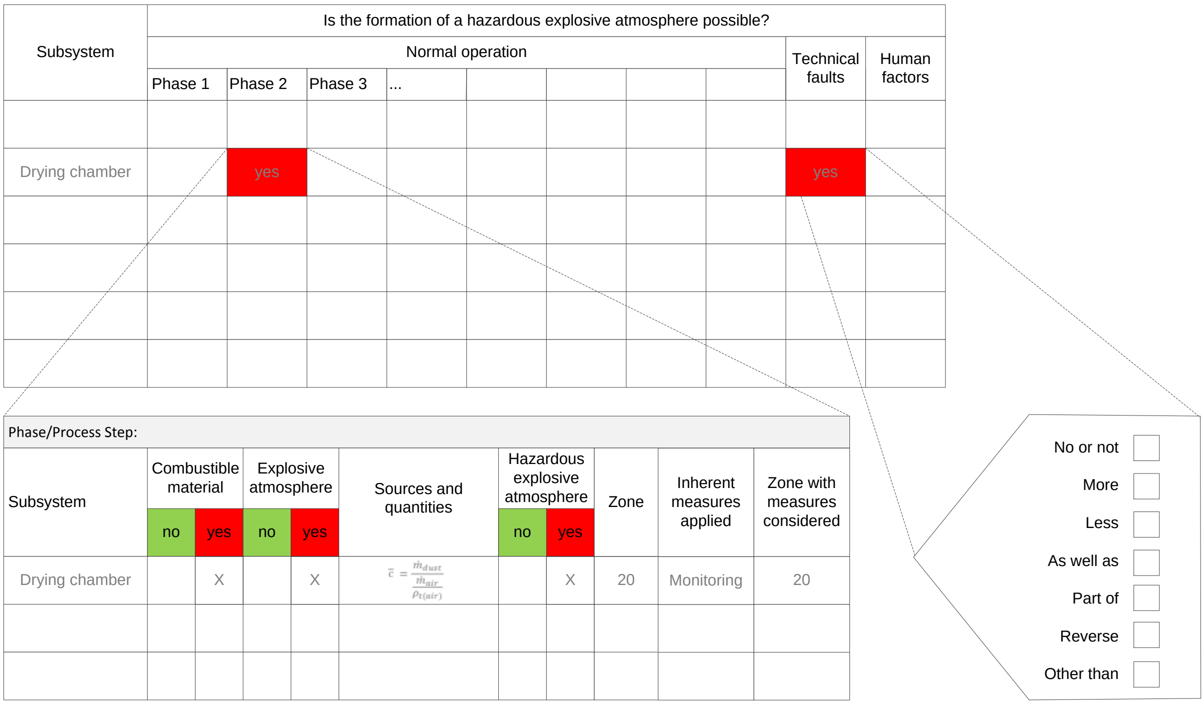

Figure 6: Tabular toolbox for step 2, formation of hazardous explosive atmosphere

If the formation of a hazardous explosive atmosphere is possible, risk reduction by inherent (primary) measures according to the technical rule (TRBS 2152 Teil 1) has to be implemented:

- Avoidance or restriction of material, which are able to form explosive atmospheres
- Avoidance or restriction of the formation of a hazardous explosive atmosphere inside an apparatus
- Avoidance or restriction of the formation of a hazardous explosive atmosphere in the surrounding of an apparatus
- Monitoring the concentration in the surrounding of an apparatus
- Measures to eliminate dust deposits in the surrounding of dust leading apparatus and vessels

After taking appropriate protective measures, the effectiveness should be checked analogously to the Plan-Do-Check-Act (PDCA) cycle. In this context it means, whether the formation can be completely excluded after the implementation of all measures. In this case, there are no further dangers beyond the assessment, which is already made and no further measures have to be taken. If this is not the case, the request scheme according to the Duktus needs to be answered further or the zone allocation needs to be continued. The Zoning as a recurring risk identification is a consequence of the given answers by now according to the formation of hazardous explosive atmosphere in combination with the defined quantities of the frequency of their occurrence.

Determination of Ignition Sources (Step 4 and 5)

To assess the effectivity of ignition sources, it is necessary to know not only all evaluated process conditions and mixture compositions, but also to check and exclude all possible 13 ignition sources (DIN EN 1127-1:2011-10) for their presence in each subsystem. If conditions can lead to the occurrence of an ignition source and under which operating conditions the source is existent, needs to be evaluated. Each subsystem should be confronted with all possible 13 ignition sources. However, it should be noted that the presence of the ignition sources is to be assessed in conjunction with different plant or equipment conditions. According to (DIN Norm 13463-1:2009), a distinction is made between the normal operation, the expected disturbances and the rare disturbances in the equipment. Therefore, if there is an ignition source existent and effective, a reference number must be formed from the predefined subsystem number and the ignition source number (see figure 7). The further classification of the risk matrix is referred to this digit. The probability of the availability of an ignitable dust-air-mixture is determined with the zoning in probabilistic concept of explosion safety. As already shown in equation (2) the total amount of effective ignition sources has to be evaluated. To fulfil the basic adoption (3) it is necessary to evaluate every ignition source in every equipment condition. Thus, for example it is essential that no effective ignition sources are present in a zone 20. This requirement is represented in figure 7 with help of the prohibition sign, which is therefore the same for each zone 20 subsystem. Correspondingly, in a zone 21, ignition sources, which can arise in rare disturbances, are acceptable. The correlation between the zoning and the ignition sources can be visualized in a matrix (see figure 7). The red area describes an unacceptable range of risk. The green area, on the other hand, describes an accepted range of risk. In the green area, the principle already described is that the calculated risk is smaller than critical risk and the assumption (3) is fulfilled. The critical risk limit is defined as the boundary layer between the green and red area in the matrix.

If the risk - depicted by the so called reference number - is in the unacceptable range, the application of certain measures allows a reduction of the risk to an acceptable level. In this *step 4 and 5* a distinction is made between causal-oriented and final-oriented measures, which were also known as preventive (secondary) and protective measures (tertiary). With respect to the illustrated example, this can be used to influence the atmosphere or the zoning, for example by temperature control. However, this measure would result in a risk reduction. Depending on the situation and measures further risk reductions could be needed to reduce the risk under the critical risk limit. Another example of a causal-oriented approach would be the use of suitable devices to avoid hot surfaces or a regular plant stop, because of monitoring and cleaning to prevent wall deposits and furthermore self-ignition in the drying chamber. If the reduction cannot be achieved by the named methods, the final-oriented approach must be followed. This can be done by design measures according to the technical rule (TRBS 2152 Teil 4), which has to be implemented:

- Explosion-resistant design
- Explosion venting
- Explosion suppression
- Explosion decoupling[2]

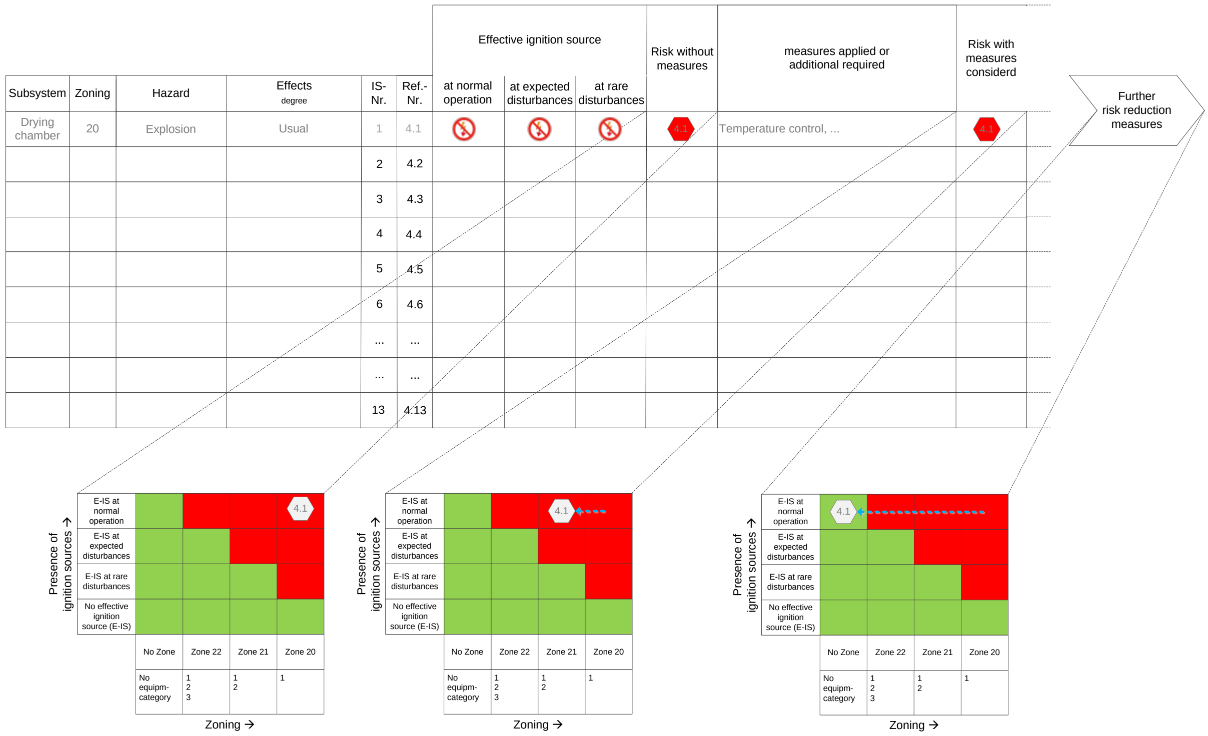

Figure 7: Tabular toolbox for step 3, effectivity of ignition sources

Conclusion

The detailed German state of the art in the field of explosion protection as well as the comprehensive legal situation provide a function of role model. Nevertheless, the implementation of these fundamental requirements should not be underestimated. Undetected negligence or failures can lead in detrimental and disastrous effects of an explosion. That is why this contribution takes up and quotes the sufficient legislations due to the evaluation steps by following the Duktus. The Duktus itself is part of the German state of the art. The description of an associated toolbox should offer equally a supporting tool for international users. Thereby the individual steps of identification and assessment of hazards is in focus, while the reduction of hazards by deriving measures, like the calculation of explosion protection by design measures is more described in general.

The assessing of explosion hazards due to the Duktus is an accepted procedure in Germany. The legal integration in the technical rules indicates that the given information complies with the state of the art and consist to the so called presumption of conformity. This indicates, in turn, that with a successful application the commitment regarding to the hazard assessment is adequate implemented and in compliance with the legal requirements. Besides this technical rules the VDI guidelines reflect also the state of the art. Furthermore, different methods of risk assessment like Zürich Hazard Analysis (ZHA) or a Failure Mode and Effect Analysis (FMEA) can be used, cf. (VDI-Richtlinie 2263 - 7.1).

The practicability of the Duktus in combination with the contributed tabular toolbox has already proven its worth within an amount of workshops with different examples of plants. In these workshops and expert exchanges the existing interest and especially need on such support tools for transparency in the assessment of explosion hazards and the required all-encompassing documentation within the explosion protection became clear. Further publications about approaches or the

[2] Explosion decoupling has to be combined with other design measures.

transfer of procedures from other fields like the Pittsburgh Coal Method (Miranda et al. 2015) demonstrate the need on an international level.

According to the new national implementation of the ATEX directive the integrated assessment of fire and explosion safety is mentioned. The meaningfulness of this expansion became clear by incidents in the past. Fires and explosions are closely linked which is already shown in the hazard triangle, respective dust explosion pentagon (figure 1), but also in the fact that fires or flames could serve as an effective ignition source for an explosion or the other way round a fire could result from an explosion, too. This increases the extent of the evaluation insofar, that not only the system and product specific hazards are in focus but also the structural fire protection of the building. For this reason there are also some first approaches for the expansion of the Duktus in terms of the integrated coherent assessment of explosion and fire hazards (Lottermann 2012).

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