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Fachbereich Holz und Metall
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Guidance for an explosion protection concept and zone classification in areas exposed to explosion hazards of various processes in electroplating and anodizing plants

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Due to the hazardous substances and to the processes used in electroplating and anodizing plants, explosive mixtures can occur within and around these plants, which can create explosion hazards.
Therefore, as part of the risk assessment in accordance with § 6 of the Gefahrstoffverordnung (GefStoffV) [1], an explosion protection document must be prepared for electroplating and anodizing plants.

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The DGUV Regel 109-602 "Electroplating industry" [2] and the product standard DIN EN 17059:2018 "Electroplating and anodizing plants - Safety requirements" [3] describe protective measures to be taken by operators and manufacturers, respectively, for the safe operation of electroplating and anodizing plants with regard to existing explosion hazards.

Up to date, there is only one published example of an explosion protection document that relates specifically to the "hard chrome plating" process in electroplating plants.

A systematic guidance for an explosion protection concept and for zone classification of potentially explosive atmospheres in various processes in electroplating and anodizing plants has not yet been provided.

This "Fachbereich AKTUELL" provides guidance on how to make use of explosion protection concept and zone classification, taking into account the results of the modelling.

1 Requirements for explosion protection documents / Legal basis

If the risk assessment has shown that there is a risk from explosions, the employer must prepare an explosion protection document in accordance with § 6 (9) GefStoffV.

This document is to show, among other things:

- how the hazard arises,
- in which areas this risk exists,
- what protective measures have been taken to:
  - prevent or restrict hazardous explosive atmospheres
  - avoid ignition of hazardous explosive atmospheres
  - limit the effects of an explosion to a harmless level.

(list acc. to § 6 Abs. 9 Satz 2 GefStoffV)

2 Explosion protection documents

2.1 Layout and structure of explosion protection documents

DGUV Information 213-106 [4], for example, recommends the following structure:

- Specification of the company/ the operating unit/ the work area
- Indication of the person responsible for the company/ the operating unit/work area, date of creation and annexes as well as accompanying documents
- Brief description of the structural and geographical conditions
- Description of the process
- Data on chemical media
- Determination of the occurrence of hazardous explosive mixtures
- Possibility of the formation of explosive mixtures
- Possibility of the formation of dangerous explosive mixtures
- Definition of areas within which hazardous explosive mixtures may occur
- Protective measures against explosion (explosion protection concept):
  - Prevention of formation of hazardous explosive mixtures
  - Determination of zones in potentially explosive areas
  - Avoidance of effective ignition sources
  - Limitation of the effects of an explosion to a harmless level
  - Organisational protective measures

See www.exinfo.de Seiten ID: #2BK8 [5] for further information, the above mentioned DGUV Information and further examples for explosion protection documents.

The risk assessment is the basis for the explosion protection document. Both documents must be kept up to date and reviewed regularly. Whenever work equipment or work processes are changed, the risk assessment and the explosion protection document must be revised, too.

2.2 The explosion protection concept

If a risk of explosion is identified within the framework of the risk assessment, it is necessary to draw up an explosion protection concept. This concept must take into account both the operational conditions and the relevant substance and operating data.

The explosion protection concept comprises measures to:

- determine the areas in which explosive atmospheres are likely to occur
- assess the explosion hazard in the previously determined areas
- classify these areas as potentially explosive atmospheres, and, if necessary, categorize them as Ex zone
- determine and implement the necessary protective measures.

This also includes the inspections to be carried out in acc. with § 7 para. 7 GefStoffV and the tests to be carried out in acc. with Annex 2 section 3 of the Betriebssicherheitsverordnung

(BetrSichV) [6] (see also § 6 (9) no. 6 GefStoffV).

An explosion protection concept can be based on known concepts specified in regulations and standards. These are often created specifically for certain types of plants. In the case of electroplating plants, such an explosion protection concept can be derived from DIN EN 17059:2018. For plants which were placed on the market before the publication of DIN EN 17059:2018, the former accident prevention regulation VBG 57 [7] can be applied.

The following sections list two examples of explosion protection concepts in accordance with DIN EN 17059:2018 and the former accident prevention regulation VBG 57.

The explosion protection concept is based on the reliable prevention of explosive atmospheres by implementing monitored ventilation measures (effective capture and extraction at the point of origin/at the process tank and, if necessary, ventilation measures).

It applies to

- Electroplating plants built and operated in accordance with DIN EN 17059:2018,

and for

- Electroplating plants built and operated in accordance with VBG 57 in the version dated 1 January 1997.

The technical ventilation system must be designed in such a way that the relevant concentration always remains sufficiently below the lower explosion limit (LEL). Extent and efficiency of the technical ventilation system determine the spatial expansion of the potentially explosive areas to be defined and the zones to be assigned. Devices and installations operating in these zones, must be of a suitable explosion-proof design (category) in accordance with ATEX Directive 2014/34/EU [8].

In processes in which only hydrogen is released, the explosion-protected devices and installations must be designed for explosion group IIC and temperature class T1.

For processes in which both oxygen and hydrogen are released and where thus oxyhydrogen gas is produced, it must be investigated which (additional) measures must be implemented to avoid effective ignition sources. One factor that must also be considered is the possibility of pronounced foaming (see DIN EN 17059:2018, 4.6.3.3.1).

If solvent vapours are released, the risk assessment must cover this as well. The required temperature class of the devices and installations to be used in explosion-protected construction must be adapted.

> Note: In many cases, devices and installations with performance of IIC T4 should be sufficient.

2.2.1 Explosion protection concept in acc. with DIN EN 17059:2018

The explosion protection concept in accordance with GefStoffV § 6, paragraph 9, number 2 applies to electroplating plants that are built and operated in accordance with DIN EN 17059:2018.

Technical ventilation within the meaning of DIN EN 17059:2018 is an object extraction system in accordance with cl. 4.6.4 of TRGS 722 [9].

The technical ventilation is designed, installed and monitored in accordance with the state of the art defined in DIN EN 17059:2018.

As soon as the exhaust air volume flow of the technical ventilation is below the design values, the formation of hydrogen is stopped by switching off the rectifiers as defined in DIN EN 17059 in such a way that the formation of hazardous explosive hydrogen-air mixtures is safely avoided.

The technical ventilation is designed in accordance with the requirements of DIN EN 17059:2018 cl. 4.6.1.3 "Technical ventilation (supply air and exhaust air plants)".

The interlocking of the power supply of the electroplating process with the technical ventilation, in which there are hazards due to the release of flammable substances (e.g. hydrogen), must comply with DIN EN 17059:2018, cl. 4.9.1.

2.2.2 Explosion protection concept in acc. with VBG 57

The explosion protection concept in accordance with GefStoffV § 6, § 9, number 2 applies to electroplating plants that are built and operated in accordance with VBG 57 in the version dated 1 January 1997.

The technical ventilation is operated and monitored in compliance with the measures defined in the former VBG 57:

- Extraction devices are required on process tanks that develop hazardous explosive atmospheres.
- Hazardous substances must be kept from penetrating into operating rooms in concentrations that are hazardous to health or in hazardous explosive atmospheres.
- A sufficient supply of fresh air must be ensured.
- An automatic warning device must be provided to indicate perturbations in ventilation and extraction systems.

(See corresponding contents of Annex A1 of the former VBG 57).

The measures taken must be based on the state of the art. Obligations concerning retrofitting in accordance with BetrSichV must be fulfilled.

3 Relevant processes with potentially explosive atmospheres

Table 1 in Annex A2 shows an overview of the chemical (electroless) and electrochemical processes in which the formation of hydrogen and oxygen during the processes can be expected to result in potentially explosive atmospheres. Both types of processes are summarized as galvanic processes.

In electrochemical processes, hydrogen is produced at the cathode by reduction of the hydrogen cations and oxygen at the anode by oxidation of the oxygen anions as part of side reactions.
The amount of hydrogen or oxygen formed is calculated using Faraday's equations (see cl. 5).

Calculations show that the amount of oxygen formed in the electrochemical processes is negligible compared to the oxygen content of 20 per cent by volume in the ambient air. The formation rate of the hydrogen formed at the cathode depends on the current strength I and the extent of the secondary reaction, i.e. the efficiency (current yield) of the main coating process on the cathodically connected workpiece surface. The hydrogen formation rate is directly proportional to the current strength I and also directly proportional to the current density as a process-specific parameter and to the total workpiece surface as a process-related parameter.

In contrast to the electrochemical processes, chemical, electroless processes produce the hydrogen by chemical reactions, for example in pickling by the acid reacting with the metal oxides on the workpiece surface, and in chemical nickel plating by the activator reacting with the workpiece surface. Table 1 shows the categorization of these processes into electrochemical and electroless process types.

Section 3 of the DGUV Regel 109-602 "Electroplating industry" identifies and defines the hazards due to fires and explosions and the associated protective measures to be taken as part of a comprehensive risk assessment for the relevant electroplating processes. In addition to the processes described in this DGUV Regel, post-dipping solutions have also been included as a process in Table 1.

The exact location ("source location") of the hydrogen formation, i.e. where the cathode is located in the process tank (location of the cathode is also of great importance for a more precise consideration and description as well as for the spatial expansion of the potentially explosive areas.

The relevant processes can be divided into cathodic and anodic processes. The decisive factor here is the electrical potential ("polarity") of the workpiece carrier and therefore the potential of the workpieces attached to the workpiece carrier. In cathodic processes, the workpiece carrier is connected as a cathode. In anodic processes, the workpiece carrier is connected as the anode and the two electrodes on the edges of the process tank form the cathodes.

The majority of the relevant processes are cathodic processes; the rarer anodic processes include electropolishing or electropolishing in pretreatment, chemical deburring and electrolytic degreasing for anodic polishing, anodizing for surface treatment and the demetallization for posttreatment.

Table 2 in Annex A2 shows the categorization of the relevant processes with potentially explosive atmospheres into cathodic and anodic processes.

4 Models of process tanks with hydrogen development

The previous section showed that the relevant electrochemical processes with the development of hydrogen are divided into cathodic and anodic processes.

Table 3 in Appendix A3 shows how a total of 16 models of process tanks with hydrogen development are derived from this, which can then be used to describe all relevant processes in practice.

The first step is to define where the hydrogen is formed during the cathodic and anodic processes and how it is then distributed within the electrolyte.

In cathodic processes, the hydrogen forms on or above the cathodically switched workpiece carrier in the centre of the process tank. It either breaks through the electrolyte surface locally above the workpiece carrier or is distributed over the entire electrolyte surface.

In the anodic processes, it forms on the two cathodically connected electrodes on the edges (long sides) of the process tank (edge electrodes), either localized on or above the two edge electrodes, or distributed over the entire electrolyte surface, for example when the electrolyte is moved, either by workpiece carrier movements and/or by circulation.

Table 3 shows the four variants that can be derived from the anodic and cathodic processes.

For further modelling and flow simulations the location and dimensions of the surfaces through which the hydrogen breaks through the electrolyte surface and is released are determined.

Fig. 1 shows the correspondingly dimensioned sketch of an assumed standard tank, figures 2 to 5 show the resulting position and dimensions of the respective hydrogen break through the surfaces on the electrolyte, shown for the sake of clarity only on the open process tank without cover.

In case of localized hydrogen evolution, the breakthrough area is defined on the basis of rectangular areas, the dimensions of which were derived from observations of corresponding processes in practice. Accordingly, the resulting rectangular area is located 0.20 m from the short edge of the process tank, resulting in a rectangle with a length of 2.60 m for a 3 m long process tank. The width of this breakthrough area is assumed to be 0.20 m.

The distance to the long sides of the process tank is defined by the type of electrolytic process and the process control, i.e. whether it is an anodic or cathodic process and whether the hydrogen evolution at the cathode is localized or delocalized due to the process. This is described in more detail below.

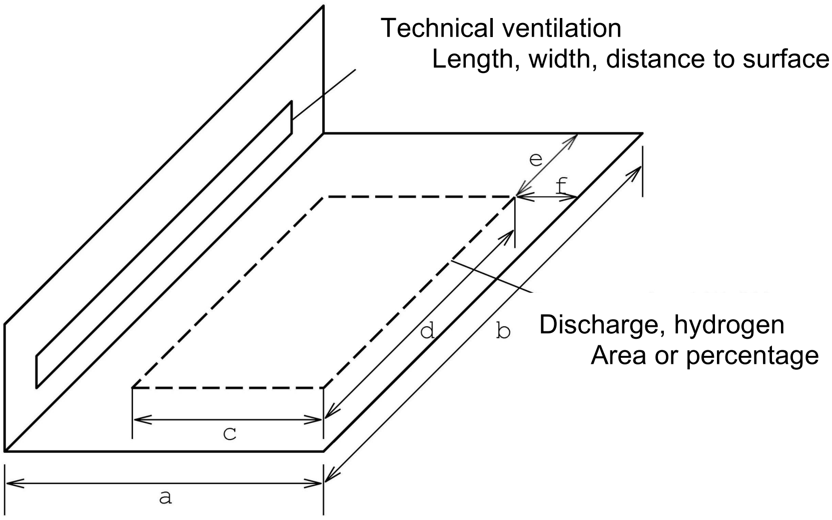
In the anodic processes, in the case of localized hydrogen evolution, two rectangular breakthrough areas of 2.60 m x 0.20 m above the two edge electrodes are assumed, located 0.10 m or 0.20 m from the long or short process tank side, or with 0.40 m mutual distance. When distributed over the entire electrolyte surface, the breakthrough area for the hydrogen corresponds to the entire surface of the process tank of 3 m x 1 m.

If cathodic processes are considered, the rectangular breakthrough area of 2.60 m x 0.20 m is located in the centre of the process tank above the workpiece carrier, with a distance of 0.40 m to the long sides and 0.20 m to the short side of the process tank. If the hydrogen is distributed over the entire electrolyte surface, the area of perforation for the hydrogen corresponds to the entire surface of the process tank of 3 m x 1 m.

For the complete definition of the process tank models, the dimensions of the height of the ventilation ducts, the detection openings and the distance of the electrolyte surface from the upper edge of the process tank (freeboard) are still required. With an assumed ventilation duct height of 0.30 m, a freeboard of 0.10 m and a height of the detection openings of 0.03 m, this results in a distance of 0.4 m from the electrolyte surface to the upper edge of the ventilation duct.

As Table 3 shows, these four process-related different variants are further subdivided according to different protective measures against explosion hazards at the process tank. These protective measures are state-of-the-art ventilation measures. Firstly, a distinction can be made between one-sided and two-sided edge extraction regarding local capture.

A further subdivision is the mechanical cover of the process tank (lid); either an open process tank without a mechanical cover or a covered process tank, resulting in a total of 16 models of process tanks with hydrogen development.

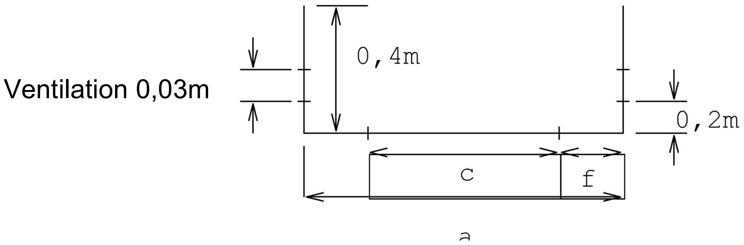


a=1,0m process tank width
b=3,0m process tank length

Technical ventilation: length 3,0m, width 0,03m,
Distance to electrolyte surface 0,2m

Hydrogen discharge area:
- Variant 1: c=a, d=b
- Variant 2: e=0,2m f=0,1m c=0,2m d=2,6m discharge surface (outside)
- Variant 3: e=0,2m f=0,4m c=0,2m d=2,6m

Front side view



Top view

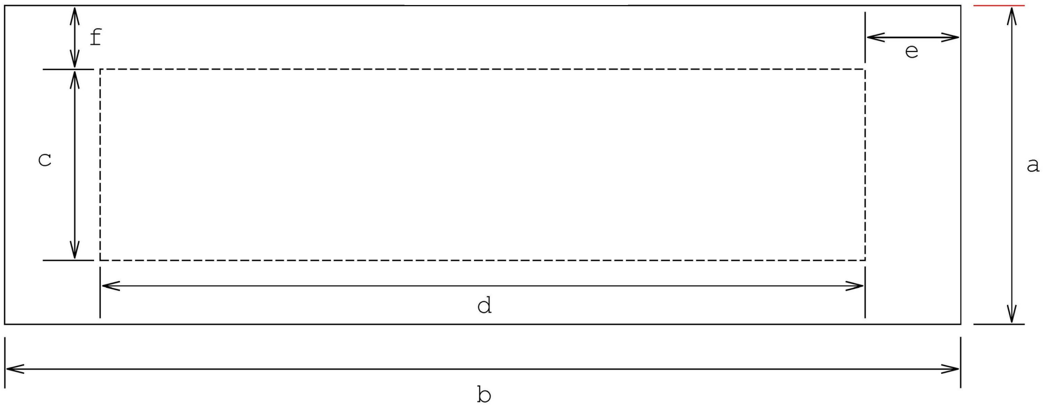


Fig. 1 – Drawing of a standard tank

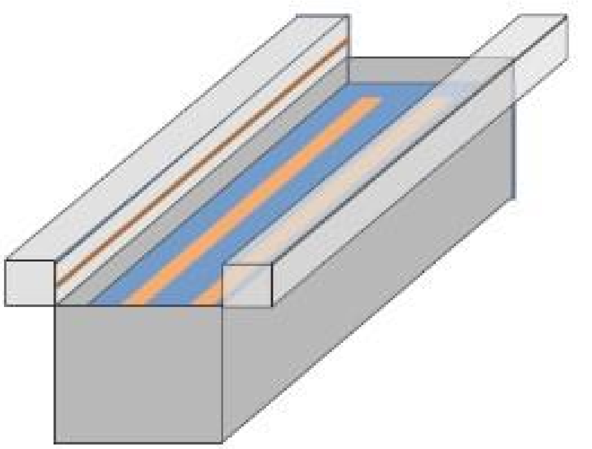


Fig. 2 – Anodic processes − localized H_2 formation on/above both edge electrodes (orange-coloured areas)

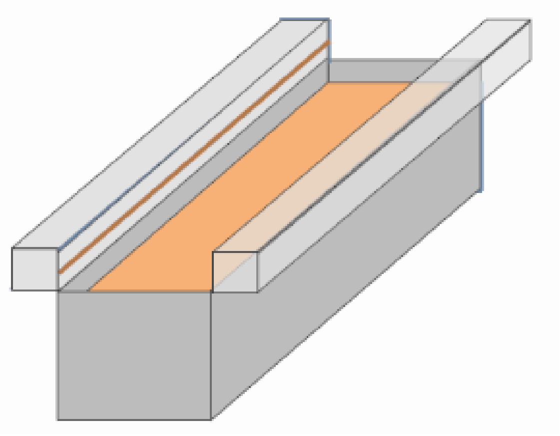


Fig. 3 – Anodic processes − H_2 formation distributed over the whole electrolyte surface (orange-coloured area)

5 Basis of calculation

5.1 Faraday's equations for determining the hydrogen and oxygen formation rate at the cathode and anode

In galvanic coating processes, metal is deposited by applying a direct voltage (e.g. copper) or, in the opposite case, removed (e.g. iron).

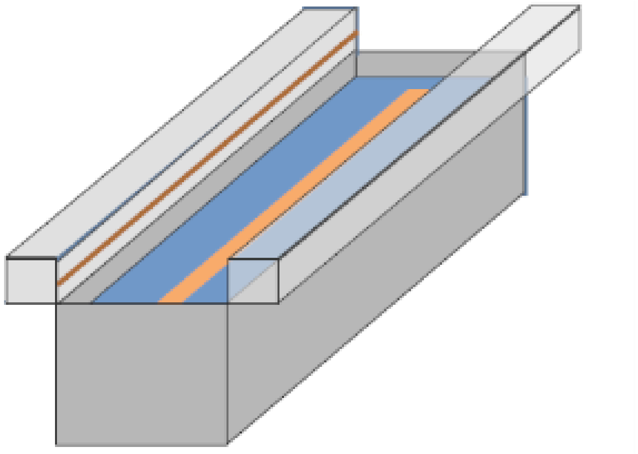


Fig. 4– Cathodic processes − localized H_2 formation in centre of/above the workpiece carrier (orange-coloured areas)

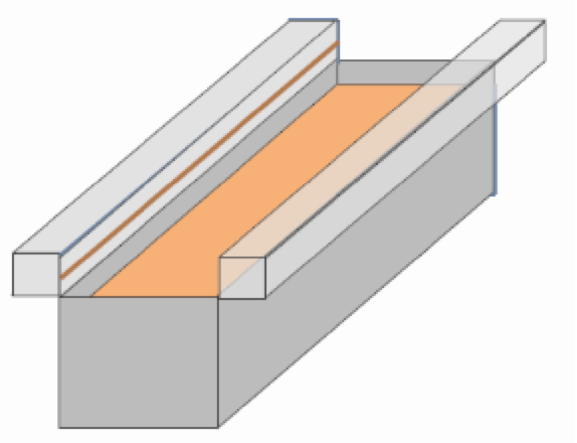


Fig. 5 – Cathodic processes – H_2 formation distributed over the whole electrolyte area (orange-coloured area)

In addition to metal conversion, a varying proportion of water is also broken down into hydrogen and oxygen, depending on the process.

The electrolysis of water is shown schematically in the following figure:

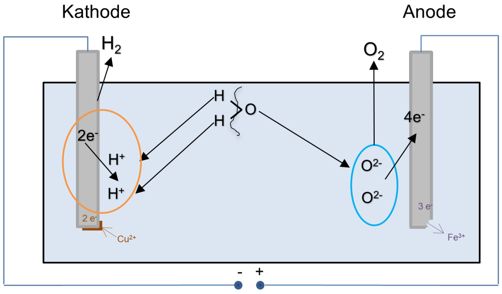


Fig. 6 – Schematic representation of the electrolysis of water

Water is split into H_3O^+ and OH^-ions by an electric field. These ions move to the anode and cathode, respectively. The oxygen releases an electron (e^-) which is taken up by the hydrogen. Oxygen is produced at the anode and hydrogen at the cathode.

The amount of gas produced is directly proportional to the current that is not used for metal deposition and can be calculated using Faraday's equation.

The amount of gas produced is directly proportional to the current that is not used for metal deposition and can be calculated using Faraday's equation.

The volume flow of hydrogen is calculated at room temperature to:

Hydrogen volume flow: $\dot{V}_{H_2}$ [m^3/h]
Current strength: I [A]
Current yield: μ [-]

$$\dot{V}_{H_2} = 4{,}5 \cdot 10^{-4} \cdot \frac{m^3}{A \cdot h} \cdot I \cdot (1 - \mu)$$

or for the volume flow of oxygen:

Oxygen volume flow: $\dot{V}_{O_2}$ [m^3/h]
Current strength: I [A]
Current yield: μ [-]

$$\dot{V}_{O_2} = 2{,}242 \cdot 10^{-4} \cdot \frac{m^3}{A \cdot h} \cdot I \cdot (1 - \mu)$$

5.2 State-of-the-art ventilation measures/ assessment of potentially explosive atmospheres

State-of-the-art electroplating plants are operated with technical ventilation in compliance with cl. 4.6.1.3 "Technical ventilation (supply air and exhaust air plants)" of DIN EN 17059:2018 "Electroplating and anodizing plants". The required volume flows of supply and exhaust air can be determined and calculated as per DIN EN 17059:2018. They depend on the design and geometry of the electroplating plant and the respective process or method. The calculation methods and equations in Annex D and the flow velocities in Annex E of the standard are used to determine the volumetric flows for the main processes commonly used in the electroplating and anodizing industry.

The hydrogen produced at the cathode is diluted by the extraction. It mixes with the extracted air. The hydrogen concentration is after complete mixing with the extracted air volume:

Hydrogen concentration: x_{H_2} [Vol.%]
Hydrogen volume flow: $\dot{V}_{H_2}$ [m^3/h]
Extracted volume flow: $\dot{V}_{ab}$ [m^3/h]

$$x_{H_2} = \frac{\dot{V}_{H_2}}{\dot{V}_{H_2} + \dot{V}_{ab}} * 100\ \%$$

The transition from the pure hydrogen escaping from the electrolyte surface to complete mixing is analyzed spatially and shown in the following CFD calculation (CFD: Computational Fluid Dynamics - see cl. 5.3 for explanations) for different types of plants and processes, allowing to derive a possible zone categorization.

As the amount of oxygen in the supply air is significantly greater than the oxygen produced by the electrolysis, the oxygen concentration in the mixture changes only insignificantly and does not need to be taken into account any further.

After starting the ventilation and then starting the electroplating process, the hydrogen concentration reaches equilibrium. This equilibrium can be calculated.

A turbulent flow prevails due to the high air volumes for capturing the hazardous substances at the plants. Therefore, no countercurrents are to be expected. The extraction systems are operated continuously so that constant flow conditions are achieved.

Depending on the distance to the lower explosion limit for hydrogen, the probability of a hazardous explosive atmosphere occurring can be estimated. If the hydrogen concentration is above the lower explosion limit for hydrogen of 4 % by volume, the mixture is ignitable.

Based on the boundary conditions for hydrogen development and for monitored technical ventilation, the following conditions are selected for zone categorization:

Since the specific place where hydrogen is produced at a certain point in time, cannot be determined exactly in advance and varies throughout the entire process, a conservative consideration regards as **zone 0** not only the range with ≥ 4 vol.% hydrogen, but also

- the entire area in which the fluid mechanical calculation indicates a hydrogen concentration of more than 1% by volume.

The fluid mechanics calculations show that the volume of this area does not represent a dangerous quantity for all the Methods considered. In reality, this volume will also not be continuous.

The further the determined concentration is below the LEL, the lower the probability that the LEL will be exceeded locally at certain times.

Continuing the convention in this sense, this results in

- **Zone 1** for a determined hydrogen concentration between 10 and 25 % of the LEL, and
- **Zone 2** for a determined hydrogen concentration between 3 and 10 % of the LEL.

From a value of less than 3 % of the LEL (determined hydrogen concentration < 0.12 % by volume), it is not to be assumed, even rarely and for a short time, that the LEL will be exceeded locally; therefore, such areas are to be regarded as **zone-free**.

Fig. 7 shows the zoning convention resulting from these considerations:

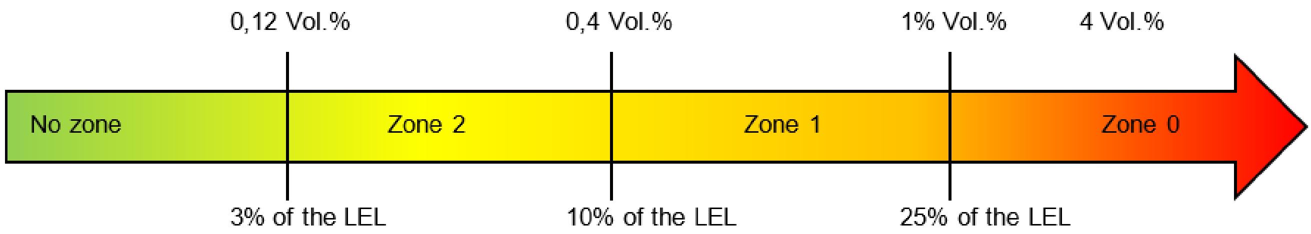


Fig. 7 – Zone categorization based on hydrogen concentrations

It should be pointed out at this point (once again) that this zoning must be adapted in the case of pronounced foam formation. In this case, the foam volume should be considered comparable to a zone 0.

An analysis and calculation of the most common processes shows that even for the two most critical processes in terms of hydrogen evolution (high current intensity, low current yield):

- Hard chrome plating (high currents, low efficiency and therefore large hydrogen volume flows)
- Electropolishing (high currents; the entire current is converted into hydrogen as metal is removed)

the dilution is sufficient even with covered process tanks (low extraction volume flows). With a technical ventilation plant designed in accordance with DIN EN 17059:2018, no zone is required in the extraction system during continuous operation. The hydrogen produced is sufficiently diluted.

5.3 Flow simulation

It takes great effort to comprehensively determine by measurement formation and spread of explosive mixtures. Such measurement can therefore usually only be carried out at specific points. A good spatial description requires many measuring points which usually cannot be measured simultaneously.

Theoretical fluid mechanics help to describe such processes mathematically, with various model equations being used: the Euler equation, the Stokes equation, the potential equation and the Navier-Stokes equation. The Navier-Stokes equation offers the most comprehensive description:

$$\rho\left(\frac{\partial\vec{v}}{\partial t}+(\vec{v}\cdot\nabla)\vec{v}\right)=-\nabla p+\mu\Delta\vec{v}+\vec{f}$$

Navier-Stokes-equation for incompressible flows

ρ	Density	$\vec{v}$	Velocity of a particle in the flow
p	Pressure	μ	Dynamic viscosity
$\vec{f}$	Volumetric force related to the unit volume		

This equation can only be solved analytically in a highly simplified form (e.g. one-dimensional and without changing the density, etc.), which is why numerical solution methods are usually used here. It takes a great effort to solve the Navier-Stokes equation directly numerically over several size scales (several metres to micrometres). Therefore, special approximations are often used, especially when modelling turbulence and boundary layers on large objects. The numerical solution of the Navier-Stokes equation requires a suitable solution method for the problem. In flow simulation, a finite volume method is usually used. The volume to be calculated is divided into volume elements, which can have any polygonal or polyhedral shape. The variables to be calculated are solved for the centre of the finite volume element.

The use of such methods is known as computational fluid dynamics (CFD).

Real objects are made up of many details. For a CFD simulation, the geometry of the objects under consideration must be simplified or abstracted to such an extent that the essential properties are retained, but the effort required for the simulation is reduced as much as possible. For this purpose, a compromise must be found between realism and effort [10].

6 Examples of plant zone categorization

The previous sections explained the principles for a plant zone categorization in the potentially explosive atmospheres that arise during the relevant processes.

Once the place of formation of the released hydrogen has been defined for the respective processes, Faraday's equation (see section 5) is used to determine its quantity and rate of formation (quantity of hydrogen/unit of time).

Note: The following illustrations are shown on pages 18ff.

Tables 5 and 6 in Annex A5 show these two values: quantity and formation rate of the hydrogen released, for the relevant processes listed in Table 1.

While in Table 5 these data were calculated from current density and total workpiece surface area as process-specific parameters, Table 6 shows the calculation of the amount of hydrogen directly from the amount of current flowing through the electrolyte or the current intensity, respectively.

In Table 5, the formation rate of the released hydrogen is used in the next step to determine the size of the exhaust air volume flow required to dilute the released hydrogen below the limit of 3 % of the LEL of hydrogen (4 % by volume).

In table 5, this value is compared with the value that results in acc. with DIN EN 17059:2018 Annex D and E for the calculated exhaust air volume flow according to the state of the art for these processes (see section 5). The exhaust air volume flows are calculated for both open and covered process tanks; in the case of open process tanks for both one-sided and two-sided edge extraction.

The comparison shows that if the technical ventilation system is designed in accordance with the state of the art defined in DIN EN17059:2018, the hydrogen released for each process is diluted below the limit of 3 % of the LEL of hydrogen (4 % by volume).

Under these conditions, no potentially explosive areas outside the process tanks should be assumed, i.e. above the detection elements of the technical ventilation (inlet openings of the ventilation ducts); this corresponds to the zone classification: "no zone". This requires that the technical ventilation is installed in accordance with the state of the art defined in DIN EN 17059:2018 and that the formation of hydrogen is safely stopped by the measures defined there as soon as the exhaust air volume flow of the technical ventilation is below the design values.

The interlocking of the power supply of the electroplating process with the technical ventilation, in which there are hazards due to the release of flammable substances (e.g. hydrogen), must meet the requirements of DIN EN 17059:2018, cl. 4.9:

- The detection of the extract air volume flow (sensors) must correspond to at least Performance Level Pl_r=c (performance level required by DIN EN ISO 13849-1:2016, Annex A [11]: Pl_r; this describes the requirement for the safety level).
- The switch-off or interlocking of the power supply (actuators) must correspond to at least one Pl_r=d.

- The power supply for a galvanic process with hydrogen development with foam formation, in which there is a risk from the release of flammable substances such as hydrogen, must be switched off or reduced to values at which an ignition hazard can be excluded when the goods are retracted and extended. This interlocking must be implemented with a PI_r=d.

Further information on the state of the art with regard to the safety requirements for control plants and safety functions is provided in subcl. 4.9.1 "Safety functions" of cl. 4.9 "Safety requirements for control plants" in DIN EN 17059:2018.

In the case of processes without external current, it is not possible to disrupt the hydrogen development by switching off the rectifiers, as is the case with electrolytic processes.

In this case, other measures according to cl. 4.6.1.3 "Technical ventilation" of DIN EN 17059:2018 must be tested for effectiveness and implemented; examples of such measures are:

- Prevent new goods from entering the plant
- Stop the lowering or lifting process by the transport plant
- Disable the automatic mode
- No automatic restart of the lowering or lifting process
- Switch off the electric immersion heaters

The discharge of process media into safety tanks specified as an efficient protective measure in cl. 4.7.5 "Thermal load" of DIN EN 17059:2018, must also be checked as an effective protective measure.

These measures, when implemented as actuators must comply with PL_r=d.

Figures 8 and 9 show that the potentially explosive areas are only inside the process tanks and that there are no potentially explosive areas outside the process tanks.

These figures 8 and 9 show examples of zone plans for open and covered process tanks and for all relevant processes with explosion hazards. The relevant processes considered here are listed in Table 5.

This consideration does not deal with the conditions between the capturing elements of the technical ventilation and the electrolyte surface, as the mixing between the formed hydrogen and the exhaust air depends on the flow conditions which change rapidly in this area.

Therefore, this degree of mixing and the resulting hydrogen concentrations are determined by the computer-aided flow simulations (CFD calculations, see cl. 5).

The systematic derivation of a zone categorization is shown below using the example of the bright chrome plating process for individual components.

Fig. 10 shows an electroplating plant with the relevant process tank in which the chrome plating process is carried out. Fig. 11 shows the process tank with this electrolytic process. The components are attached to the workpiece carrier, which is located in the centre of the process tank. The workpiece carrier and components are connected as a cathode so that the hydrogen is localized on their surface and breaks through the electrolyte surface directly above the workpiece carrier. The breakthrough surface is clearly visible as a notch in the orange-coloured wetting agent in fig. 10.

Results of the CFD simulations

The bright chrome plating process was selected as an example to illustrate the results of the CFD simulations, using the process parameters for hydrogen evolution and the exhaust air volume flows summarised in Table 7 in Appendix A5.

In order to keep the computational effort to a minimum, a greatly simplified geometry reduced to the essentials was considered [10].

A distinction is made between the two applications of an open process tank without a lid and a process tank with a lid.

Figures 12 and 13 show the two geometries used. The tank has a rectangular floor plan of 1 m x 3 m. The strips visible on the right and left walls are the capture openings of the edge extraction system on both sides. The volume in which the calculations were carried out is the cuboid resulting from the visible side walls. The hydrogen enters over the entire surface of the base. The incoming hydrogen volume flow results from the process under consideration. The volume flow of the extraction system meets the requirements of DIN EN 17059:2018. The air can flow in via the non-coloured surfaces, except for the floor.

The distribution of hydrogen is a decisive factor for assessing the hazards caused by explosions in the considered process. There are many ways to visualize this. First, the hydrogen distribution should be considered in cross-section (with the cut surface across the centre of the process tank) and in longitudinal section (cut surface lengthwise through the center of the process tank).

More detailed information is provided by the subsequent visualization of areas of equal concentration, so-called isoconcentration areas.

Figures 14 to 23 show the hydrogen distribution over the electrolyte surface of the process tank resulting from the CFD calculations, with figures 14 to 18 relating to an open process tank, and figures 19 to 23 relating to a covered process tank.

These figures show the hydrogen distributions in longitudinal section and cross-section of the process tank, with figures 14 (longitudinal section) and 15 (cross-section) showing the hydrogen distributions for the open process tank, and figures 19 and 20 showing the hydrogen distributions for the covered process tank.

The hydrogen distributions in the longitudinal and cross-sections are shown as the concentration of hydrogen in per cent by volume (% H_2); the concentration range shown is 0 % - 4 %, i.e. it extends from 0 % to the LEL of hydrogen of 4 %.

The hydrogen distribution as isoconcentration area is shown as concentration in relation to the lower explosion limit (% of the LEL).

As explained in Section 5, the following categorization of zones was assumed for the assessment of explosion hazards based on hydrogen concentrations with correspondingly large volumes: Zone 0: hydrogen concentration ≥ 25 % of the LEL, Zone 1: 10 % ≤ hydrogen concentration < 25 % of the LEL, zone 2: 3 % ≤ hydrogen concentration < 10 % of the LEL, and no zone: hydrogen concentration < 3 % of the LEL.

Therefore, these 3 concentration areas were chosen for the coloured representation of the isoconcentration areas of hydrogen; the area colour corresponds to the colour scheme in the representation of these areas as a "concentration scheme" from section 5:

- The isoconcentration area at 3 % of the LEL shows the boundary between the areas without zone allocation and zone 2 (area shown in green).
- The isoconcentration area at 10 % of the LEL shows the boundary between the areas of zone 2 and zone 1 (area shown in yellow).
- The isoconcentration area at 25 % of the LEL shows the boundary between the areas

of zone 1 and zone 0 (area shown in red).

Fig. 14 shows a longitudinal section of the open process tank with a pronounced concave concentration curve for the hydrogen, with the minimum in the centre of the process tank and the two maxima just below the edge of the process tank on its smaller side.

The cross-section of the process tank in figure 15 also shows a concave concentration curve for the hydrogen, with the Minimum - as in Fig. 14 - in the centre of the process tank and the two maxima just below the collection openings of the edge extraction on both sides.

The resulting isoconcentration areas of the hydrogen in the open process tank are shown in figure 16 (3 % of the LEL), Fig. 17 (10 % of the LEL) and figure 18 (25 % of the LEL).

The isoconcentration surface of the hydrogen at 25 % of the LEL (figure 18) also shows a concave basic contour, the boundaries of which, as intersection lines with the walls of the process tank, lie clearly below the capture openings of the edge extraction on both sides.

The isoconcentration area at 10 % of the LEL (figure 17) shows a convex area in the centre of the process tank that is superimposed on the concave basic structure compared to Fig. 16; this isoconcentration area is closer to the capture openings of the edge extraction on both sides than the area at 25 % of the LEL.

If the isoconcentration surface at 3 % of the LEL is considered (fig. 16), its convex curvature in the centre of the process tank is much more pronounced than that in fig. 17. This results in a distinctly curved isoconcentration surface, the boundaries of which, as intersection lines with the walls of the process tank, are close to the capture openings of the edge extraction on both sides.

In the covered process tank, the concentration profiles for the hydrogen in the longitudinal section (Fig. 19) and cross-section (Fig. 20) show an overall more convex concentration curve for the hydrogen compared to the open process tank.

The longitudinal section in Fig. 19 shows a convex concentration curve for the hydrogen, with a maximum in the centre of the process tank and the two minima just below the edge of the process tank on its smaller side.

In the cross-section (Fig. 20), two maxima symmetrical to the centre of the process tank interrupt the convex course shortly before the capture openings of the edge extraction on both sides.

The resulting isoconcentration areas of the hydrogen in the covered process tank are shown in Fig. 21 (3 % of the LEL), Fig. 22 (10 % of the LEL) and Fig. 23 (25 % of the LEL).

The course of these isoconcentration areas for the covered process tank is basically similar to that already described for the open process tank.

Starting from the concave isoconcentration surface at 25 % of the LEL (Fig. 23), the convex curvature in the centre of the process tank increases significantly at 10 % of the LEL in Fig. 22 and 3 % of the LEL in Fig. 21.

This convex curvature of the isoconcentration surfaces in the centre of the process tank is more pronounced in the covered process tank than in the open process tank.

As the conditions at the edges of the process tanks are nevertheless comparable, the isoconcentration areas of the hydrogen also end below the collection openings of the edge extraction system in the covered process tank.

According to figures 14 to 23, the areas with hydrogen concentrations up to 25 % of the LEL are localised only in the volume below the collection openings of the edge extraction system on both sides.

This allows the conclusion that no g.e.A of hydrogen ("no zone") exists in the detection openings if monitored technical ventilation in accordance with DIN EN 17059:2018 is assumed.

The CFD calculations show that the area in which the proportion of hydrogen in air corresponds to more than 25 % of the LEL (area 4 in figure 24) is limited to the volume inside the process tank, which is located below an imaginary boundary line formed by the capture openings of the edge extraction on both sides ("vents") (boundary line 1 in figure 24).

The area in which, according to the CFD calculations, there is no such concentration of hydrogen begins well below the detection openings, with the exact distance to the detection opening depending on the electroplating process under consideration and the type of plant.

The volume between the electrolyte surface and the lower edge of the extraction (boundary line 1 in figure 24) is characterized by the fact that the concentration of the released hydrogen drops from 100 % to small fractions of the LEL. The transition takes place over a few cm and does not allow a differentiated distinction of individual zones, e.g. due to the uneven electrolyte surface or the flow conditions.

When assessing the area of the potentially explosive atmosphere of hydrogen below limit line 1 or in area 4, it must be taken into account that an explosive atmosphere in hazardous quantities does not exist everywhere.

The coherent volume of explosive atmosphere is locally changing and only occasionally and limited above a value of 10 litres or greater than 1/10,000 of the existing room volume. Therefore, a zone 1 is to be assumed for area 4.

The potentially explosive areas are shown in figures 8 and 9. They are located inside the process tanks between the electrolyte surface and the lower edge of the detection device (edge extraction) and are categorized as Zone 1. There are no potentially explosive areas outside the process tanks.

If devices that represent a potential source of ignition during operation are to be brought into or installed in this area, they should therefore fulfil the following requirements in accordance with ATEX Directive 2014/34/EU for a Zone 1 for explosion protection:

- Device group II (surface devices)
- Device category 2G (zone 1 and zone 2 for gases)
- Explosion group IIC (hydrogen)
- Temperature class T1 (hydrogen).

These requirements have an impact on electrical and non-electrical equipment such as the gear wheels of drum drives, level sensors or electrical heating plants. In the ventilation plant (area "2" in the exhaust air duct in figure 24), there is no area with a potentially explosive atmosphere in normal operation, as the ventilation plant is located well above the identified potentially explosive area. Even if the ventilation system malfunctions, for example in the event of a drop in fan performance (area "3" in the exhaust air duct in 24), there is no area with a potentially explosive atmosphere in normal operation.

The requirement for this is that the technical ventilation is monitored in accordance with the state of the art defined in DIN EN 17059. As soon as the exhaust air volume flow of the technical ventilation is below the design values, the formation of hydrogen is stopped by switching off the rectifiers as defined in DIN EN 17059 in such a way that the formation of hazardous explosive hydrogen-air mixtures is safely avoided.

There are only small quantities of hydrogen in the ventilation plant when the ventilation is restarted and there is no segregation.

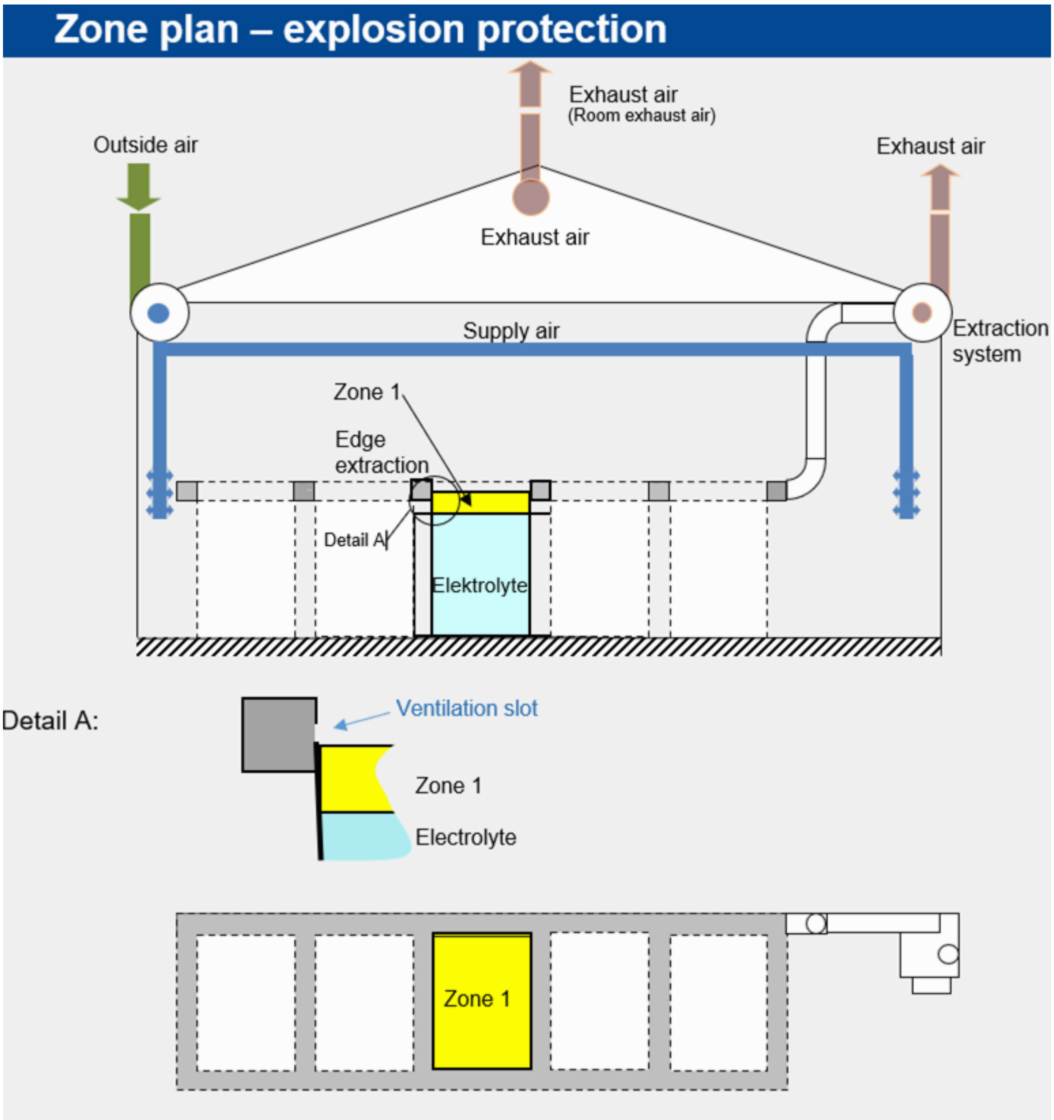


Fig. 8 − Open process tank showing the potentially explosive areas inside the process tank between the electrolyte surface and the air ventilation duct (rim ventilation). There are no potentially explosive areas outside the process tanks.

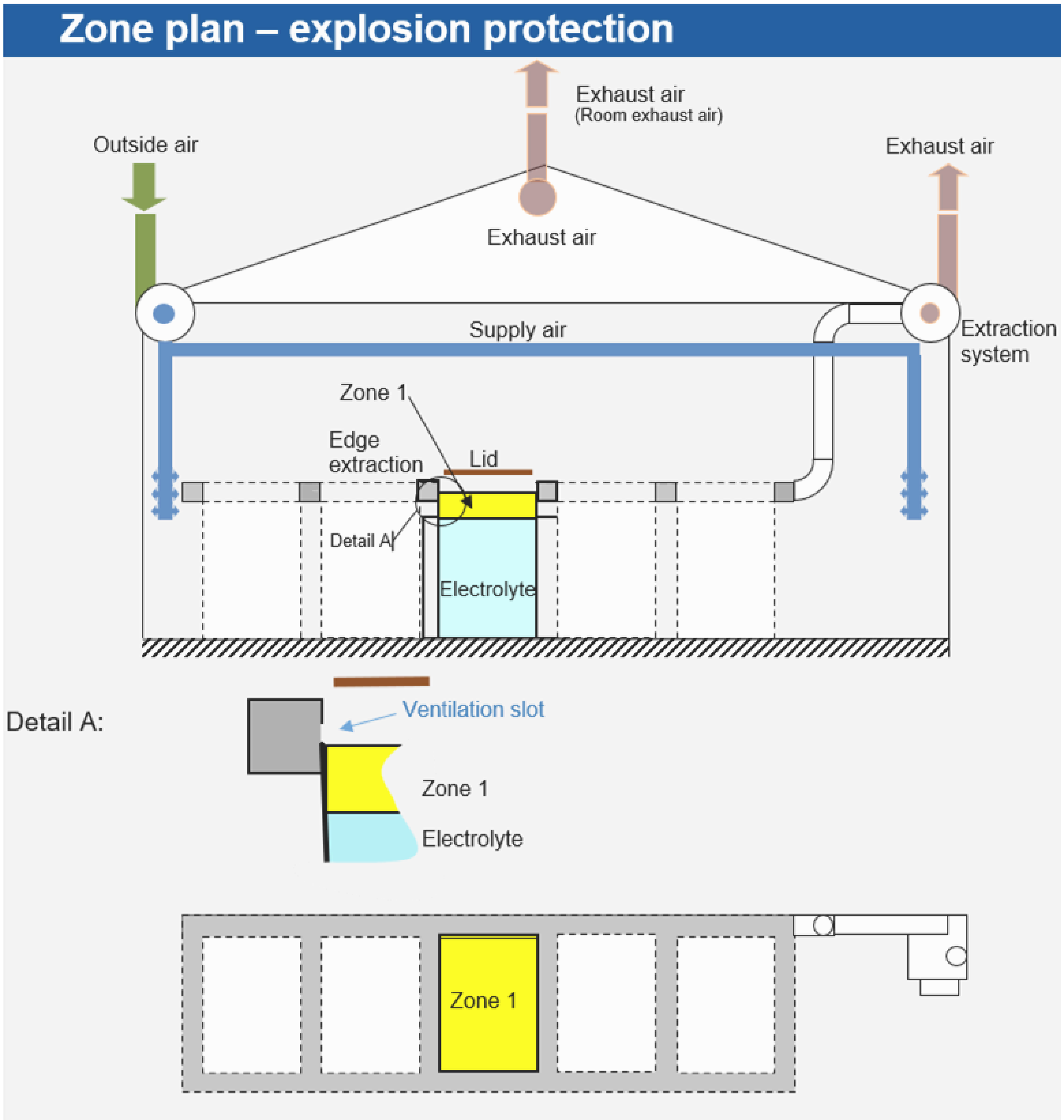


Fig. 9 − Covered process tank showing the potentially explosive areas inside the process tank between the electrolyte surface and the air ventilation duct (rim ventilation). There are no potentially explosive areas outside the process tanks.

Fig. 10 – Chromium plating process tank with wetting agent on the electrolyte surface.

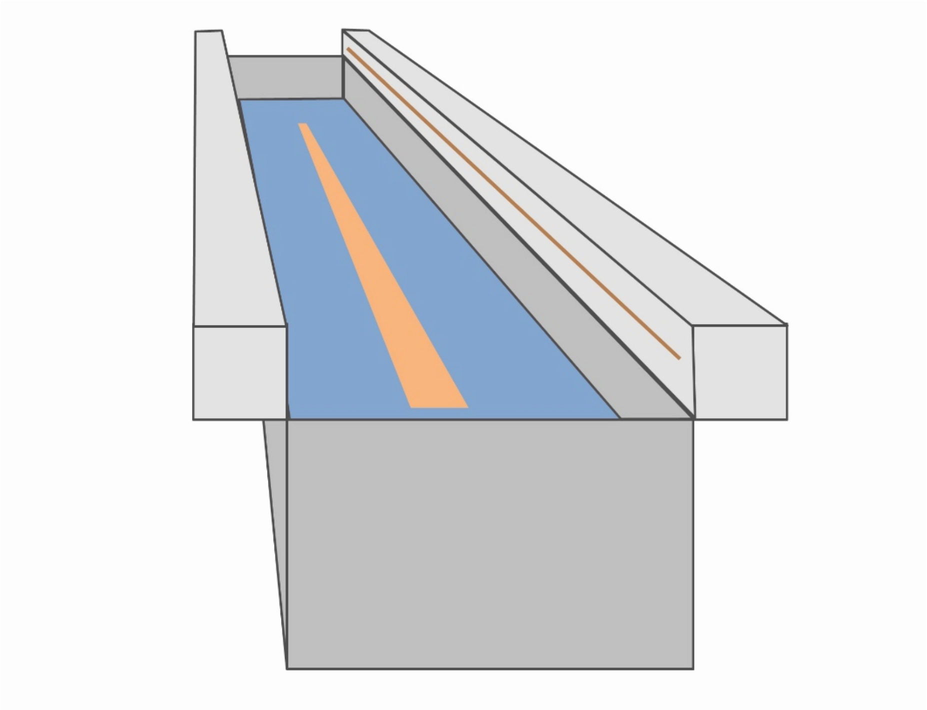


Fig. 11 − Schematic of a process tank in which the chromium plating process takes place as a cathodic process with localized hydrogen formation on the workpiece carrier or components (orange coloured area)

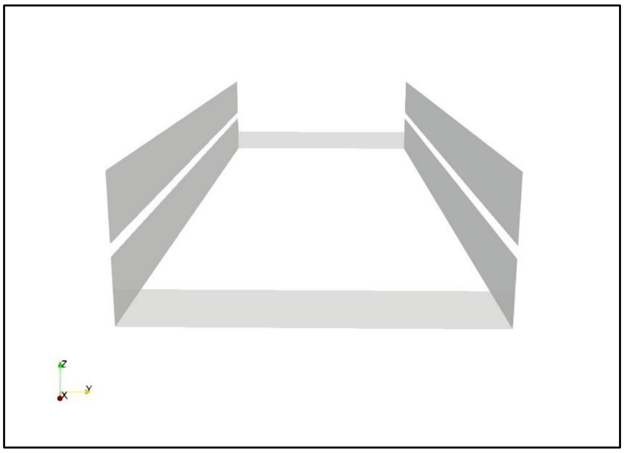


Fig. 12 − Open process tank without mechanical cover (lid)

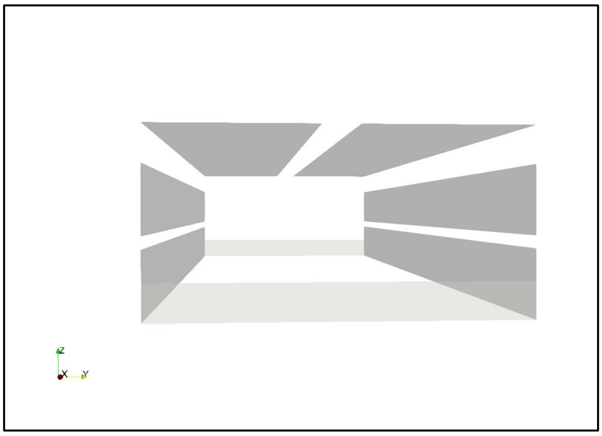


Fig. 13 − Covered process tank with mechanical cover (lid)

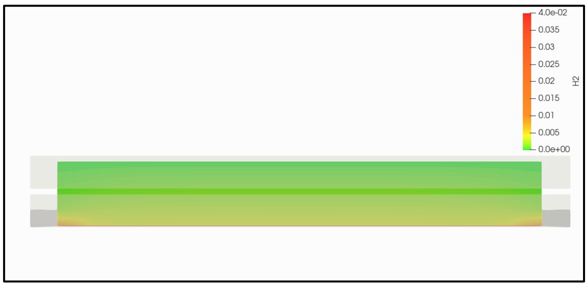


Fig. 14 − Open process tank, hydrogen distribution according to CFD calculations in longitudinal section. The concentration range shown is 0 - 4 % hydrogen by volume.

The concentrations shown are between 0% of the LEL (green) and 100 % of the LEL (red).

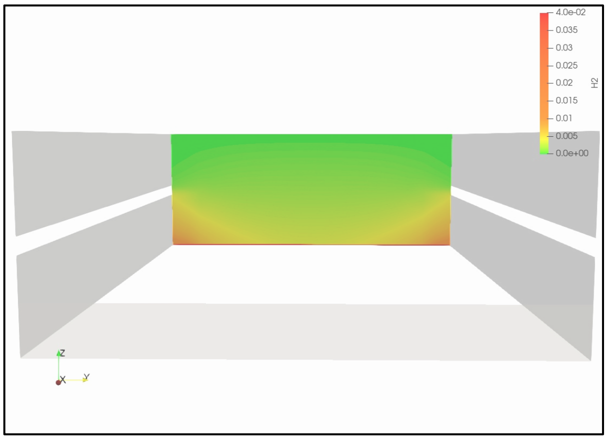


Fig. 15 − Open process tank, hydrogen distribution according to CFD calculations in cross-section.

Shown concentration range 0 - 4 % hydrogen by volume.

The concentrations shown are between 0 % of the LEL (green) and 100 % of the LEL (red).

The volume above the areas shown (figs. 16-23) always shows smaller concentrations, volumes below always show larger concentrations.

A closer look at the area of the detection openings shows average concentrations of hydrogen there, which are always lower than the LEL values shown as isoconcentration areas.

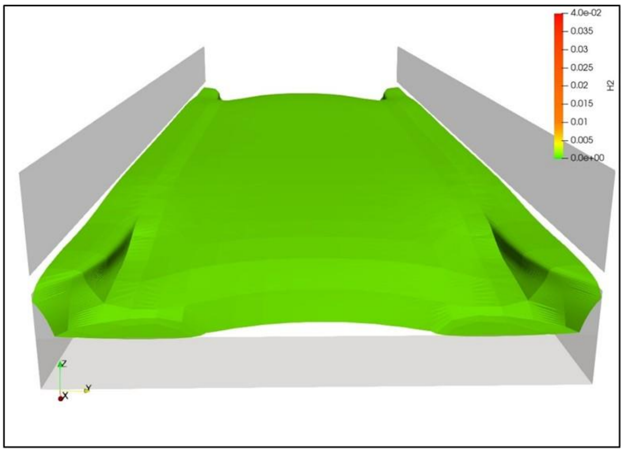


Fig. 16 − Open process tank: Isoconcentration area at 3 % of the LEL.

The volume above this area always has smaller concentrations, volumes below it always have larger concentrations.

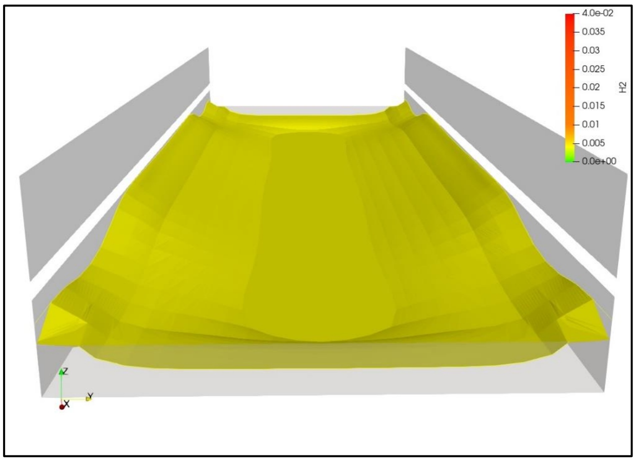


Fig. 17 − Open process tank: Isoconcentration area at 10 % of the LEL.

The volume above this area always has smaller concentrations, volumes below it always have larger concentrations.

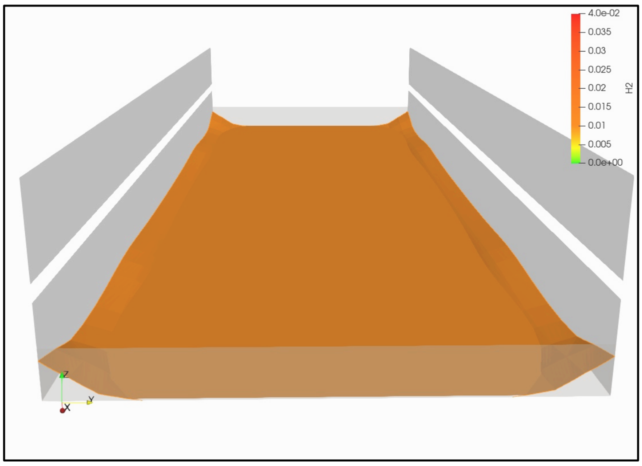


Fig. 18 − Open process tank: Isoconcentration area at 25 % of the LEL.

The volume above this area always has smaller concentrations, volumes below it always have larger concentrations.

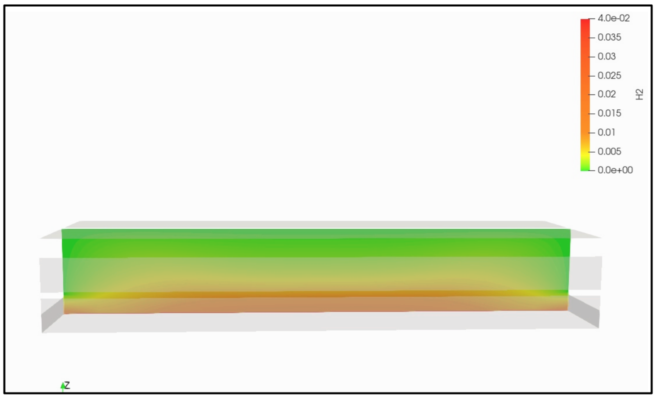


Fig. 19 − Covered process tank: Hydrogen distribution according to CFD calculations in longitudinal section.

Shown concentration range 0 - 4 % hydrogen by volume.

The concentrations shown are between 0 % of the LEL (green) and 100 % of the LEL (red).

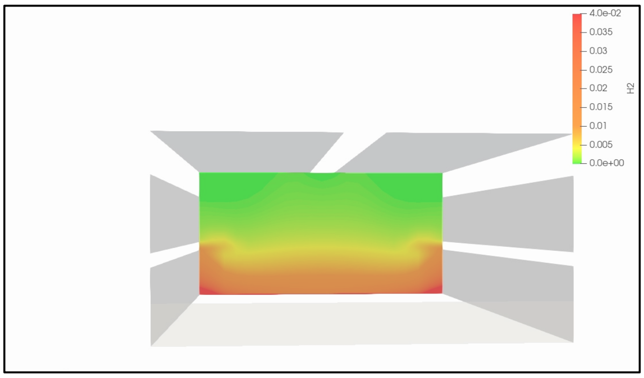


Fig. 20 − Covered process tank, hydrogen distribution according to CFD calculations in cross-section.

Shown concentration range 0 - 4 % hydrogen by volume.

The concentrations shown are between 0 % of the LEL (green) and 100 % of the LEL (red).

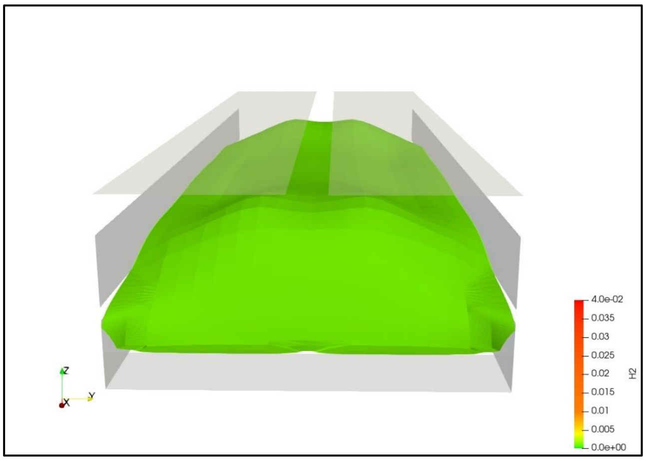


Fig. 21 − Covered process tank: Isoconcentration area at 3 % of the LEL.

The volume above this area always has smaller concentrations, volumes below it always have larger concentrations.

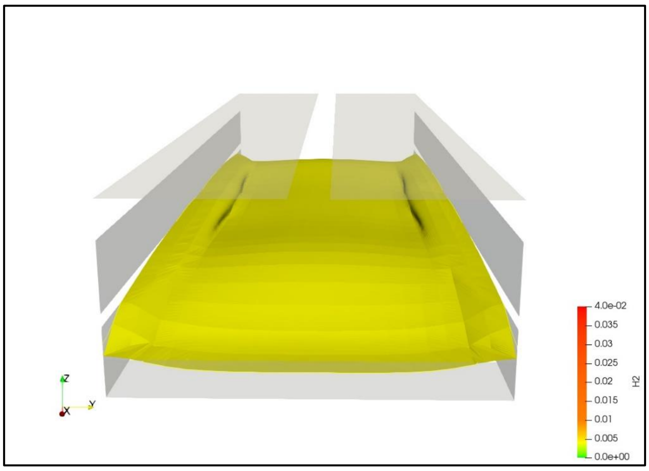


Fig. 22 − Covered process tank: Isoconcentration area at 10 % of the LEL.

The volume above this area always has smaller concentrations, volumes below it always have larger concentrations.

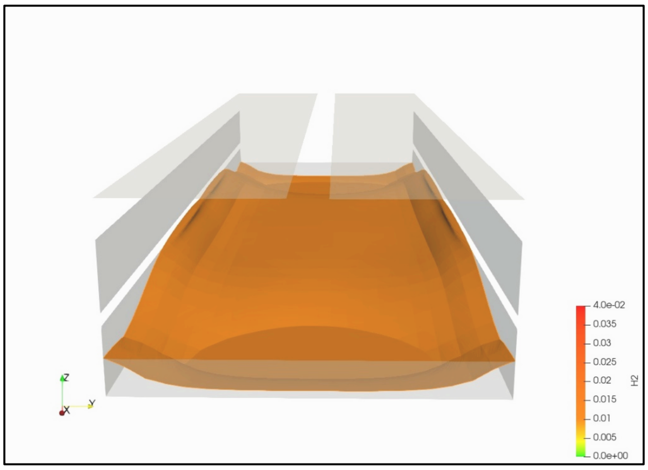


Fig. 23 − Covered process tank: Isoconcentration area at 25 % of the LEL.

The volume above this area always has smaller concentrations, volumes below it always have larger concentrations.

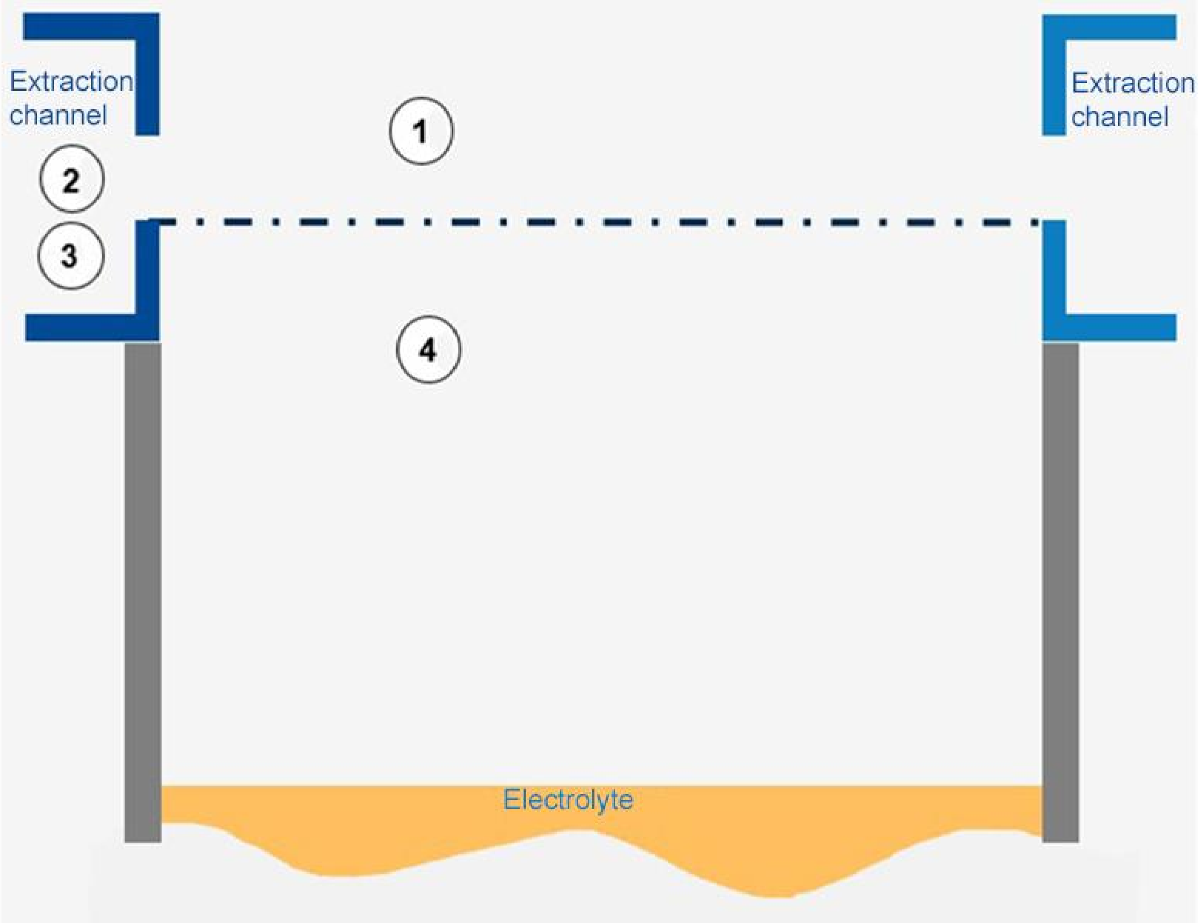


Fig. 24 − Areas considered (for determination of zones) in the process tank and in the ventilation system (cross-section) - Results of the CFD calculations

7 Summary and scope of application

This "Fachbereich AKTUELL" derives examples for areas with potentially explosive atmospheres in galvanizing plants and supports the preparation of explosion protection documents.

An analysis of all relevant processes shows that dilution is sufficient even for the most critical processes in terms of hydrogen development. With technical ventilation designed in accordance with DIN EN 17059:2018, there is no zone outside the process tanks and in the continuously operated extraction system itself. The resulting hydrogen is sufficiently diluted. The area between the electrolyte surface and the lower edge of the detection openings of the technical ventilation is classified as a zone 1.

This "Fachbereich AKTUELL" thus supplements the risk assessment in acc. with DGUV Regel 109-602 "Electroplating sector" and DGUV Information 209-006 "Electroplating" [12] by providing assistance for all relevant processes in electroplating and anodizing plants with explosion hazards for the applied explosion protection concept and zone classification.

The provisions of individual laws and ordinances remain unaffected by these "Fachbereich AKTUELL" remain unaffected. The requirements of the statutory provisions apply without restriction.

In order to obtain complete information, it is necessary to consult the relevant regulatory texts.

This "Fachbereich AKTUELL" is the translation of the German edition 03/2022. In any case, the German original shall prevail. No liability is accepted for translation errors.

The Wood and Metal Division is made up of representatives of the accident insurance institutions, government agencies, social partners, manufacturers and operating companies, among others.

Further "Fachbereich AKTUELL" or Information sheets from the Wood and Metal Division are available for download on the Internet [13].

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[3] DIN EN 17059 „Electroplating and anodizing plants - Safety requirements“, Version October 2018, Beuth Verlag Berlin

[4] DGUV Information 213-106 „Explosionsschutzdokument“, Ausgabe Juni 2021, DGUV Berlin

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[7] Former accident prevention regulation VBG 57 Electrolytic and chemical surface treatment; electroplating, in the version dated 01 January 1997, withdrawn in February 1999

[8] Directive 2014/34/EU of the European Parliament and of the Council of 26 February 2014 on the harmonisation of the laws of the Member States relating to equipment and protective systems intended for use in potentially explosive atmospheres (recast)

[9] TRGS 722 „Vermeidung oder Einschränkung gefährlicher explosionsfähiger Gemische“, BAuA, Februar 2021

[10] “CFD Simulation, Interpretation and Graphical Representation of Hydrogen Distribution in Electroplating Plants”, Masterarbeit Farshad Fahim, Otto von Guericke University of Magdeburg, Faculty for Process and Plants Engineering, Magdeburg, April 2022

[11] DIN EN ISO 13849-1 Safety of machinery - Safety-related parts of control systems - Part 1: General principles for design, version June 2016, Beuth Verlag Berlin

[12] DGUV Information 209-009 „Galvanisieren, Ausgabe November 2019, DGUV Berlin

[13] Internet: www.dguv.de/fb-holzundmetall Publikationen oder www.bghm.de Webcode: <626>

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Fig.s 2, 3, 4, 5, 6, 7, 8, 9, 11, 24:

Project team for DGUV-Projekt 2019-0011 „Explosion protection documents for potentially explosive areas of various processes in electroplating plants“.

Fig. 10:

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The DGUV's specialist areas are supported by the accident insurance funds, the sector-specific social accident insurance institutions and the organization DGUV itself. The German Social Accident Insurance Institution for the woodworking and metalworking industry is the lead accident insurance institution for the specialist area of woodworking and metalworking and is therefore the first point of contact at federal level for questions relating to occupational safety and health in this area.

The following committees and working groups were involved in the development of this Fachbereich AKTUELL:

- BGHM, Prevention Division, Department Wood and metalworking technologies, SG Automotive engineering, maintenance, surface technology
- BG ETEM, Prevention Department, PZ Augsburg
- BG RCI, FB RCI, SG Explosion Protection
- Qubus Planung und Beratung Oberflächentechnik GmbH
- PTB Braunschweig, Working group 3.72, Explosion processes under non-atmospheric conditions
- BG ETEM, PZ Cologne, Electroplating.

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Appendix

A1 Annex to the explosion protection concept (Cl. 2)

The majority of the documents cited or referenced in this earlier accident prevention regulation VBG 57 have already been repealed and are no longer valid.

Extracts from the former accident prevention regulation VBG 57 „Electrolytic and chemical surface treatment; electroplating“

Extraction and ventilation

§ 12

(1) Open reaction tanks for waste water treatment and open baths that generate gases, vapours or mists in concentrations that are hazardous to health or hazardous explosive atmospheres must be equipped with extraction systems that also capture the gases, vapours or mists that are generated when loading and unloading workpieces.

(2) Exhaust air ducts must be designed and routed in such a way that gases, vapours or mist in concentrations that are hazardous to health or hazardous explosive atmospheres cannot penetrate into operating rooms. A sufficient supply of fresh air must be ensured.

Implementation instruction:

Hazardous concentrations of gases, vapours or mists can be produced, for example, in chrome baths, electrolytic degreasing baths, degreasing baths with organic solvents, electrolytic dementalization baths, baths for electrolytic and chemical polishing, cyanide baths, alkaline pickling agents for light metals, acidic pickling, anodic oxidation (anodizing), air agitated baths, etching machines and in waste water treatment (e.g. nitrite detoxification by oxidation using sodium hypochlorite, cyanide detoxification, chromium VI reduction).

Hazardous concentrations of hazardous substances are present, for example, if the maximum workplace concentration (MAK value) or technical guideline concentration (TRK value) is exceeded. The applicable MAK and TRK values can be found in the "List of MAK values (TRGS 900)" (ZH 1/401) listed.

The spatial arrangement of the extraction openings must take into account the temperature and density of the pollutant or waste material. In the case of gases, vapours or mists that are hazardous to health and whose density is higher than that of air, it is advisable to route the air from top to bottom, i.e. to provide extraction at floor level. In the case of hot gases, vapours or mists with a density lower than that of air, e.g. heated solvent vapours, ceiling extraction is appropriate. Room ventilation and extraction at the point of origin or discharge must be coordinated. Air containing harmful substances must not be channelled through the breathing zone of employees. When working with pickling agents containing nitric acid (yellow burning), this must be achieved by means of extraction devices which enclose the tanks in such a way that the free openings required for inserting the workpieces are minimized. If hazardous vapours also develop when the workpieces are transferred from one bath to the other, the extraction system must be designed in such a way that it encloses at least these two baths.

The output of the extraction system may not be reduced by room ventilation or by subsequent installations or conversions. Ventilation should cover the entire room if possible. Regarding the basic requirements for the ventilation of workspaces, reference is made to Section 5 of the Workplace Ordinance. Section 6 of the Workplace Ordinance must be considered with regard to the appropriate room temperature. It is particularly important to provide an automatic warning device to indicate faults in ventilation systems (see Section 5 of the

Workplace Ordinance) and extraction systems (see Section 14 of the Workplace Ordinance).

In general, the formation of a hazardous explosive atmosphere is not to be expected if the concentration of the solvent vapour-air mixture or hydrogen-air mixture is sufficiently far below the lower explosion limit. This is generally the case with solvents if the concentration is already below the TLV (MAK-Wert) at any point and at all times in the entire room.

Care must be taken to ensure separate ducting when discharging the exhaust air if the respective exhaust air flows can react dangerously with each other, e.g. exhaust air from baths containing acids and cyanide due to the risk of hydrogen cyanide formation (hydrocyanic acid).

Chemical and mechanical agents can reduce the occurrence of harmful gases, vapours or mist. Depending on the composition of the bath contents, these include foaming agents (wetting agents) and floating elements made of plastic (e.g. plastic balls for chrome baths).

If hydrofluoric acid vapours can develop, the requirements of the leaflet "Fluorine hydroxide (hydrofluoric acid) and inorganic fluorides" (ZH 1/161) must be observed.

See also

- Ordinance on electrical installations in potentially explosive atmospheres (ElexV),
- §§ 44 and 45 UVV "General regulations" (VBG 1),
- "Guidelines for the prevention of Hazards due to explosive atmospheres with a collection of examples - Explosion protection guidelines - (EX-RL)" (ZH 1/10),
- "Guidelines for plants for cleaning workpieces with solvents (solvent cleaning plants)" (ZH 1/562).
- …

Marking of the process tanks

§ 15

The employer must ensure that baths in which hydrogen develops with the formation of foam are labelled with a notice indicating a possible explosion hazard.

…

(2)

…

Extraction and ventilation

§ 16

The employer must ensure that the ventilation and extraction systems are effective and are inspected by an expert at appropriate intervals, but at least once a year.

Implementation instruction:

This requirement includes that - as long as gases, vapours, mists or dusts occur in concentrations or quantities that are hazardous to health - the equipment for technical ventilation, e.g. fans, ventilation ducts, baffles, supply and exhaust air openings, must not become ineffective.

Care must also be taken to ensure that the extraction systems must be in operation during heating and cooling and during breaks in use. In individual cases, it may also be sufficient to cover unused baths that emit gases or vapours that are hazardous to health.

If, despite extraction and ventilation, it is not possible to safely exclude that the limit values (MAK, TRK values) are exceeded, the UVV "General regulations" (VBG 1) Respiratory protection must be provided by the employer and used by the insured persons. This may be the case, for example, when preparing preparations, filling hazardous substances, working in containers or confined spaces.

Respiratory protective equipment must also be kept ready for operational faults.

See also "Respiratory protection data sheet" (ZH 1/134).

Time intervals for the tests are appropriate if, taking into account the operational circumstances, they ensure that hazards are prevented by reducing the effectiveness of the ventilation and extraction equipment.

Experts are persons who, due to their professional training and experience, have sufficient knowledge in the field of ventilation plants and are familiar with the relevant national health and safety regulations, accident prevention regulations, guidelines and generally recognised Rules of technology (e.g. DIN standards, VDE regulations) to such an extent that they can assess the safe working condition of ventilation plants and handle the necessary measuring equipment.

…

Degreasing, cleaning and drying with solvents

§ 22

(1) For degreasing, cleaning and drying with solvents, the entrepreneur must take special protective measures against health, fire and explosion hazards.

Implementation instruction:

Solvents are organic liquids, in particular halogenated hydrocarbons (chlorinated hydrocarbons [ClHCs] and hydrofluorocarbons [HFCs], hydrocarbons, alcohols, ketones and mixtures of the above substances). This requirement is met if there are no objects with hot surfaces (e.g. no welding, cutting) on which the halogenated hydrocarbons can decompose and no naked flames (smoking ban!) or sparks (grinding) in areas of 5 m around solvent cleaning plants in which halogenated hydrocarbons are used.

See also

- Ordinance on the limitation of emissions of light liquid halogenated hydrocarbons 2nd BImSchV -,
- Ordinance on electrical installations in potentially explosive atmospheres (ElexV),
- §§ 43 and 44 UVV "General regulations" (VBG 1),
- "Guidelines for the prevention of Hazards due to explosive atmospheres with a collection of examples - Explosion protection guidelines - (EX-RL)" (ZH 1/10),
- "Guidelines for plants for cleaning workpieces with solvents (solvent cleaning plants)" (ZH 1/562),
- Leaflet: "Chlorinated hydrocarbons" (ZH 1/194),
- Leaflet: "Solvents" (ZH 1/319),
- "Code of practice for handling fluorocarbons - HFC code of practice" (ZH 1/409),
- "Cold cleaner data sheet" (ZH 1/425).

According to Annex II Section 1.3.4 of the Hazardous Substances Ordinance, cleaning work with gasoline is prohibited due to the benzene it contains.

(2) The employer must ensure that only tetrachloroethene (perchloroethylene), specially stabilized chlorinated hydrocarbons or specially stabilized solvent mixtures are used to clean machined workpieces made of aluminium or aluminium-containing materials with chlorinated hydrocarbons. The suitability of the specially stabilized chlorinated hydrocarbons and solvent mixtures for this purpose must be verified by an expert opinion from a test centre appointed by the employers' liability insurance association.

Implementation instruction:

The testing centre designated by the employers' liability insurance association is, for example, the Federal Institute for Materials Research and Testing (BAM), Unter den Eichen 87, 12205 Berlin. Information on the current status of tested specially stabilised chlorinated hydrocarbons and specially stabilised solvent mixtures can be obtained from the Central Office for Accident Prevention and Occupational Medicine of the Federation of Institutions for Statutory Accident Insurance and Prevention, 53754 Sankt Augustin.

Process tanks with hydrogen formation

§ 23

The employer must ensure that the power supply is interrupted before inserting and removing the workpieces of the process tanks in which hydrogen develops with foam being generated.

Implementation instruction:

This applies to the immersion of light metal hollow profiles in lye due to the lively formation of hydrogen. When immersing light metal workpieces with a large surface area, the bath liquid must also be prevented from foaming over, e.g. by maintaining a sufficient distance between the surface of the liquid and the edge of the tank or by placing smaller batches in the baths.

A2 Annex to relevant processes with potentially explosive areas (cl. 3)

Table 1 – Relevant processes with potentially explosive areas

Pre-treatment process	**Process type**
Polishing, chemical deburring	electrochemical
Electrolytic degreasing	electrochemical
Pickling	electroless
Surface treatment	
Hard chrome plating	electrochemical
Bright chrome plating	electrochemical
Electroless nickel plating	electroless
Galvanic nickel plating	electrochemical
Cyanide copper plating	electrochemical
Acidic copper plating	electrochemical
Cyanide galvanizing	electrochemical
Alkaline galvanizing	electrochemical
Gilding	electrochemical
Silver plating	electrochemical
Acidic tinning	electrochemical
Alkaline tinning	electrochemical
Anodizing	electrochemical
Post-treatment	
Demetallizing	electrochemical
Post-dipping solutions	electroless

Table 2 – Relevant processes with categorisation into anodic and cathodic processes

Pre-treatment process	**Cathodic / anodic process**
Polishing, chemical deburring	anodic
Electrolytic degreasing	cathodic / anodic
Pickling	-
Surface treatment	
Hard chrome plating	cathodic
Bright chrome plating	cathodic
Electroless nickel plating	-
Galvanic nickel plating	cathodic
Cyanide copper plating	cathodic
Acid copper plating	cathodic
Cyanide galvanizing	cathodic
Alkaline galvanizing	cathodic
Gilding	cathodic
Silver plating	cathodic
Acidic tinning	cathodic
Alkaline tinning	cathodic
Anodizing	anodic
Post-treatment	
Demetallizing	anodic
Post-dip solutions	-

A3 Annex to models of process tanks with hydrogen formation (cl. 4):

Table 3 Process-related variants from anodic and cathodic processes

Anodic processes **Workpiece carrier = anode**								**Cathodic processes** **Workpiece carrier = cathode**							
localised H_2 development at/above both edge electrodes Variant 2 c = 0,2m ; d = 2,6m ; e = 0,2m ; f = 0,1m free-standing process tank				H_2 development distributed over the entire electrolyte surface Variant 1 c = a = 1m; d = b = 3m free-standing process tank				localised H_2 development in the centre of/above the workpiece carrier Variant 3 c = 0,2m ; d = 2,6m ; e = 0,2m ; f = 0,1m free-standing process tank				H_2 development distributed over the entire electrolyte surface Variant 1 c = a = 1m; d = b = 3m free-standing process tank			
One-sided edge extraction		Two-sided edge extraction		One-sided edge extraction		Two-sided edge extraction		One-sided edge extraction		Two-sided edge extraction		One-sided edge extraction		Two-sided edge extraction	
Open process tank	Covered process tank	Open process tank	Covered process tank	Open process tank	Covered process tank	Open process tank	Covered process tank	Open process tank	Covered process tank	Open process tank	Covered process tank	Open process tank	Covered process tank	Open process tank	Covered process tank

A4 Derivation of the equation for the formation of hydrogen (cl. 5)

Table 4 – Symbols, constants, indices and substance values

Designation	Symbol	Unit	Hydrogen	Oxygen
Mass	m	kg		
Molar mass	M	kg/kmol	2,01588 kg/kmol	16,00 kg/kmol
Current	I	A		
Time	t	s		
Faraday constant	F	96.484.560 A s/kmol		
Value	z	-	2	4
Density	ρ	kg/m³	0,0899 kg/m³	1,4289 kg/m³
Volume	V	m³		
Volume flow	$\dot{V}$	m³/s		
Temperature	T	K		
Power yield	µ	-		
20°C and 1013 HPa	Index R			
0°C and 1013 HPa	Index 0			

Faraday's equation can be used to derive the relationship between the formation of hydrogen through electrolysis and the current used.

The Faraday equation is:

$$m = \frac{M*I*t}{z*F} \quad (1)$$

The equation for the density can be used to convert the mass or mass flow into the volume or volume flow.

$$\rho = \frac{m}{V}$$

$$V = \frac{m}{\rho}$$

For the corresponding currents

$$\dot{V} = \frac{m}{\rho * t}$$

If the density ρ is added to the Faraday equation (1), the result is:

$$\frac{m}{t * \rho} = \frac{M}{z * F * \rho} * I$$

$$\dot{V} = \frac{M}{z*F*\rho} * I \quad (2)$$

Formation of hydrogen

Under the ambient conditions found in plants (20°C and 1013 hPa), the air and hydrogen can be regarded as an ideal gas and a simple temperature correction can be made using the general gas equation.

This means that the material values (density) can be used for normal conditions (0°C and 1013 hPa):

$$\frac{\rho_R}{\rho_0} = \frac{T_0}{T_R}, \quad \Rightarrow \quad \rho_R = \rho_0 * \frac{T_0}{T_R}$$

$$\dot{V} = \frac{M}{z * F * \rho_0} * \frac{T_R}{T_0} * I$$

$$\dot{V} = \frac{2{,}01588}{2 * 96.484.560 * 0.0899} * \frac{293}{273} * \frac{kg * kmol * m^3}{kmol * s * kg} * {}^{I}/_{A}$$

$$\dot{V} = 0{,}000000124 * \frac{m^3}{s} * {}^{I}/_{A}$$

Converted to the unit m³/h (multiplied by 3600 s/h)

$$\dot{V} = 0{,}00045 * \frac{m^3}{h} * {}^{I}/_{A}$$

In galvanic processes, only part of the current is converted into hydrogen through electrolysis. The current yield μ describes what proportion is utilized in the desired conversion and deposition of the metal on the workpiece surface. The remainder (1-μ) is converted into hydrogen:

$$\dot{V}_{H_2} = 4{,}5 \cdot 10^{-4} \cdot \frac{m^3}{A \cdot h} \cdot \mathrm{I} \cdot (1 - \mu)$$

Formation of oxygen

The formation of oxygen is linked to the formation of hydrogen via the stoichiometric equation of electrolysis:

$$2\,H_2O \rightarrow 2\,H_2 + O_2$$

The equation derived above therefore also applies to the formation of oxygen at the anode.

If the material values of oxygen are inserted into the equation, the result is

$$\dot{V}_{O_2} = \frac{16{,}00}{4 * 96.484.560 * 1{,}4289} * \frac{293}{273} * (1 - \mu) * \frac{kg * kmol * m^3}{kmol * s * kg} * {}^{I}/_{A}$$

$$\dot{V}_{O_2} = 6{,}2278 * 10^{-8} * (1 - \mu) * \frac{m^3}{s} * {}^{I}/_{A}$$

$$\dot{V}_{O_2} = 2{,}24 \cdot 10^{-4} \cdot \frac{m^3}{A \cdot h} \cdot I \cdot (1 - \mu)$$

A5 Annex on examples for a systematic classification of zones (cl. 6)

Table 5 – Quantity and formation rate of hydrogen, calculated from current density and total workpiece surface as well as required flow velocities v and exhaust air volume flows V' according to standard DIN EN 17059

Process	**Parameters**			**Amount of hydrogen formed/formation rate m^3/h**	**Exhaust air volume flow V' for c(H_2) < 3 % of the LEL m^3 / h**	**Flow velocity v open process bath DIN EN 17059 Annex E m/s**	**Exhaust air volume flow V' for open process bath DIN EN 17059 one-sided edge extraction m^3 / h**	**Exhaust air volume flow V' for open process bath DIN EN 17059 two-sided edge extraction m^3 / h**	**Flow velocity v at openings of the covered process bath DIN EN 17059 Annex E m/s**	**Exhaust air volume flow V' for covered process bath DIN EN 17059 one-sided/two-sided edge extraction m^3 / h**
	Current density I A / dm^2	**Deposit rate n µm/min**	**Power yield µ**							
Pre-treatment										
Polishing, chemical deburring	15,00	2,250	0,00	4,0954	3.408,74	0,50	10.533,03	9.492,90	0,90	4.536,00
Electrolytic degreasing	6,50	0,001	0,00	0,9761	812,42	0,75	15.799,55	14.239,35	0,65	3.276,00
Surface treatment										
Hard chrome plating	50,00	1,000	0,10	12,2862	10.226,23	0,75	15.799,55	14.239,35	1,30	10.764,00
Bright chrome plating	10,00	0,070	0,30	1,0512	874,91	0,75	15.799,55	14.239,35	1,30	6.552,00
Nickel plating, galvanic	10,00	1,210	0,95	0,0751	62,49	0,50	10.533,03	9.492,90	0,90	4.536,00
Copper plating, cyanide	3,00	1,280	0,97	0,0135	11,25	0,25	5.266,52	4.746,45	0,65	3.276,00

Process	Parameters									
	Current density I A / dm^2	Deposit rate n µm/min	Power yield µ	Amount of hydrogen formed/formation rate m^3/h	Exhaust air volume flow V' for $c(H_2) < 3$ % of the LEL m^3 / h	Flow velocity v open process bath DIN EN 17059 Annex E m/s	Exhaust air volume flow V' for open process bath DIN EN 17059 one-sided edge extraction m^3 / h	Exhaust air volume flow V' for open process bath DIN EN 17059 two-sided edge	Flow velocity v at openings of the covered process bath DIN EN 17059 Annex E m/s	Exhaust air volume flow V' for covered process bath DIN EN 17059 one-sided/two-sided edge extraction m^3 / h
Cyanide copper plating with polarity reversal	3,00	2,000	0,91	0,0417	34,68	0,25	5.266,52	4.746,45	0,65	3.276,00
Copper plating, acidic)*	-	-	-	-	-	-	-	-	-	-
Galvanising, cyanide	3,00	0,770	0,90	0,0450	37,50	0,25	5.266,52	4.746,45	0,65	3.276,00
Galvanising, alkaline	3,00	0,350	0,50	0,4095	340,87	0,25	5.266,52	4.746,45	0,65	3.276,00
Galvanising, acidic	3,00	0,840	0,98	0,0164	13,63	0,25	5.266,52	4.746,45	0,65	3.276,00
Refining, gold	1,00	0,560	0,88	0,0180	15,00	0,25	5.266,52	4.746,45	0,65	3.276,00
Refining, silver	1,00	0,630	0,91	0,0015	1,25	0,25	5.266,52	4.746,45	0,65	3.276,00
Tin plating, acidic	1,00	0,480	0,95	0,0075	6,25	0,38	8.005,10	7.214,60	0,65	3.276,00
Tin plating, alkaline	1,00	0,230	0,90	0,0150	12,50	0,38	8.005,10	7.214,60	0,65	3.276,00
Anodizing	1,50	0,390	0,00	0,4778	397,69	0,50	10.533,03	9.492,90	0,90	4.536,00

Table 6 − Quantity and formation rate of hydrogen, calculated from the amount of current flowing through the electrolyte or the current intensity

Process	Volume flor	Power yield	Current in A					Current in A				
			10	100	1.000	10.000	30.000	10	100	1.000	10.000	30.000
			Hydrogen formation rate					Hydrogen concentration**				
	m³/h	-	m³/h	m³/h	m³/h	m³/h	m³/h	Vol.%	Vol.%	Vol.%	Vol.%	Vol.%
Pre-treatment process, process type												
Polishing, chemical deburring	4600	0	0,00452	0,0452	0,452	4,52		0,00010	0,00098	0,00983	0,09816	
	9500	0	0,00452	0,0452	0, 452	4,52		0,00005	0,00048	0,00476	0,04756	
	10550	0	0,00452	0,0452	0,452	4,52		0,00004	0,00043	0,00428	0,04283	
Electrolytic degreasing	14500	0	0,00452	0,0452	0,452	4,52		0,00003	0,00031	0,00312	0,03116	
Surface treatment												
Hard chrome plating	10500	0,1	0,00407	0,04068	0,4068	4,068	12,204	0,00004	0,00039	0,00387	0,03873	0,11609
	14500	0,1	0,00407	0,04068	0,4068	4,068	12,204	0,00003	0,00028	0,00281	0,02805	0,08409
	15800	0,1	0,00407	0,04068	0,4068	4,068	12,204	0,00003	0,00026	0,00257	0,02574	0,07718
Bright chrome plating	6600	0,3	0,00316	0,03164	0,3164	3,164		0,00005	0,00048	0,00479	0,04792	
Galvanic nickel plating	4600	0,95	0,00023	0,00226	0,0226	0,226		0,00000	0,00005	0,00049	0,00491	
Cyanide copper plating	3300	0,97	0,00014	0,00136	0,01356	0,1356		0,00000	0,00004	0,00041	0,00411	
Cyanide copper plating with polarity reversal	3300	0,91	0,00041	0,00407	0,04068	0,4068		0,00001	0,00012	0,00123	0,01233	

Process	Volu-me flor	Power yield	Current in A					Current in A				
			10	100	1.000	10.000	30.000	10	100	1.000	10.000	30.000
			Hydrogen formation rate					Hydrogen concentration**				
	m³/h	-	m³/h	m³/h	m³/h	m³/h	m³/h	Vol.%	Vol.%	Vol.%	Vol.%	Vol.%
Acidic copper plating*	-	-	-	-	-	-	-	-	-	-	-	-
Cyanide galvanizing	3300	0,9	0,00045	0,00452	0,0452	0,452		0,00001	0,00014	0,00137	0,01370	
Alkaline galvanizing	3300	0,5	0,00226	0,0226	0,226	2,26		0,00007	0,00068	0,00685	0,06844	
Acidic galvanizing	3300	0,98	9E-05	0,0009	0,00904	0,0904		0,00000	0,00003	0,00027	0,00274	
Gilding	3300	0,88	0,00054	0,00542	0,05424	0,5424		0,00002	0,00016	0,00164	0,01643	
Silver plating	3300	0,99	4,5E-05	0,00045	0,00452	0,0452		0,00000	0,00001	0,00014	0,00137	
Acidic tinning	3300	0,95	0,00023	0,00226	0,0226	0,226		0,00001	0,00007	0,00068	0,00685	
Alkaline tinning	3300	0,9	0,00045	0,00452	0,0452	0,452		0,00001	0,00014	0,00137	0,01370	
Anodizing	4600	0	0,00452	0,0452	0,452	4,52		0,00010	0,00098	0,00983	0,09816	
	6500	0	0,00452	0,0452	0,452	4,52		0,00007	0,00070	0,00695	0,06949	
	9500	0	0,00452	0,0452	0,452	4,52		0,00005	0,00048	0,00476	0,04756	
	10550	0	0,00452	0,0452	0,452	4,52		0,00004	0,00043	0,00428	0,04283	

* No significant hydrogen formation, process is therefore not considered

** The concentrations refer to the resulting concentration of hydrogen after dilution by the volume flow specified in column 2 (calculated for extraction).

Table 7 − Parameters for the CFD calculations - hard chrome plating (1), electropolishing (2) and bright chrome plating (3) processes; hydrogen Formation rates and exhaust air volume flows for the processes under consideration in accordance with DIN EN 17059:2018 Annex D and E.

Anodic processes **Workpiece carrier = anode**	**Cathodic processes** **Workpiece carrier = cathode**	
Process: Electropolishing; I = 9.000 A	**Process: Bright chrome plating; I = 6.000 A**	**Process: Hard chrome plating; I = 30.000 A**
H_2 formation rate: V' (H_2) = 4,068 m^3/h	**H_2 formation rate: V' (H_2) = 1,898 m^3/h**	**H_2 formation rate: V' (H_2) = 12,024 m^3/h**
Two-sided edge extraction (open process tank):	**Two-sided edge extraction (open process tank):**	**Two-sided edge extraction (open process tank):**
Exhaust air volume flow (open tank) $V'_{DIN\ EN\ 17059}$ = 9.500 m^3/h V'(H2) / (V'(H2) +V'_{Luft}) $_{offen}$ = 0,000428	Exhaust air volume flow (open tank) $V'_{DIN\ EN\ 17059}$ = 14.250 m^3/h V'(H_2) / (V'(H_2) +V'_{Abluft})$_{,\ offen}$ = 0,000131	Exhaust air volume flow (open tank) $V'_{DIN\ EN\ 17059}$ = 14.250 m^3/h V'(H_2) / (V'(H_2) +V'_{Abluft})$_{,\ offen}$ = 0,000841
One-sided edge extraction (open process tank):	**One-sided edge extraction (open process tank):**	**One-sided edge extraction (open process tank):**
Exhaust air volume flow (open tank) $V'_{DIN\ EN\ 17059}$ = 10.550 m^3/h V'(H2) / (V'(H2) +$V'_{exh.}$) $_{open}$ = 0,000428	Exhaust air volume flow (open tank) $V'_{DIN\ EN\ 17059}$ = 15.800 m^3/h V'(H_2) / (V'(H_2) +V'_{Abluft})$_{,\ offen}$ = 0,000120	Exhaust air volume flow (open tank) $V'_{DIN\ EN\ 17059}$ = 15.800 m^3/h V'(H_2) / (V'(H_2) +V'_{Abluft})$_{,\ offen}$ = 0,000772
One-sided/two-sided edge extraction (covered process tank):	**One-sided/two-sided edge extraction (covered process tank):**	**One-sided/two-sided edge extraction (covered process tank):**
Air velocity in acc. with Annex E of DIN EN 17059 at the openings of the covered process tank: 0,90 m/s	Air velocity in acc. with Annex E of DIN EN 17059 at the openings of the covered process tank: 1,30 m/s	Air velocity in acc. with Annex E of DIN EN 17059 at the openings of the covered process tank: 1,30 m/s
Exhaust air volume flow (covered process tank): $V'_{DIN\ EN\ 17059}$ = 4.600 m^3/h V'(H2) / (V'(H2) +V'_{Abluft}) $_{abgedeckt.}$ = 0,000884	Exhaust air volume flow (covered process tank): $V'_{DIN\ EN\ 17059}$ = 6.500 m^3/h V'(H_2) / (V'(H_2) +V'_{Abluft})$_{,\ abgedeckt.}$ = 0,000292	Exhaust air volume flow (covered process tank): $V'_{DIN\ EN\ 17059}$ = 10.500 m^3 / h V'(H_2) / (V'(H_2) +V'_{Abluft})$_{,\ abgedeckt}$ = 0,001161