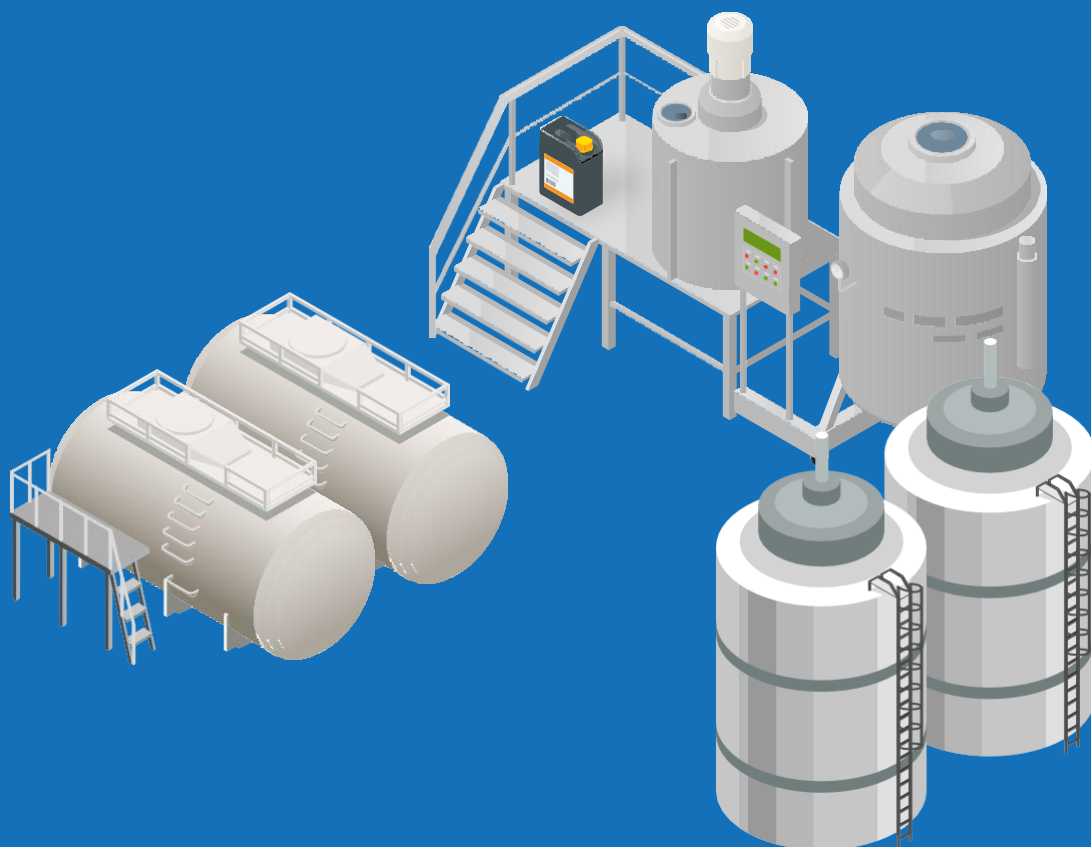




# BULK STORAGE GUIDELINE

(Published in March 2021; last updated in June 2026)



# PREFACE

(Published in March 2021; last updated in June 2026)

This guideline is supported and maintained by the Cefic Hydrogen Peroxide Technical Committee, which consists of the following companies:

**ARKEMA**  
**BELINKA** Perkemija  
**ERCROS**  
**EVONIK**  
**KEMIRA**  
**NOURYON**  
**SOLVAY**

The development of this guideline is in accordance with our Responsible Care commitment to all stakeholders throughout the life cycle of hydrogen peroxide. Its purpose is to provide a single source of guidance for controlling the risks of bulk storage which is intended to be widely available to all stakeholders. It is the policy of our companies to achieve the standards embodied in the guidance.

The updated version of this document can be found on the website: [www.peroxygens.org](http://www.peroxygens.org)

Peroxygens Sector Group

# **BULK STORAGE GUIDELINE**

(Updated in June 2026)

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# Purpose and scope of the guideline

**Responsible Care** is a voluntary initiative of the chemical industry.

The objective: continuous improvement in the areas of environmental protection, health and safety. This guideline on the **Bulk Storage of Hydrogen Peroxide** is an illustration of this commitment.

End-uses of hydrogen peroxide have undergone major development during recent decades: in 2019 more than five million tons 100% of hydrogen peroxide are used world-wide in multiple applications e.g. pulp and paper, chemical, home and personal care. Recognised as environmentally friendly in so far as its by-products, water and oxygen, do not represent any risk, hydrogen peroxide remains nevertheless a chemical for which storage and handling are safe only as long as strict safety principles are known and respected by all.

The European producers of hydrogen peroxide, members of the Cefic Peroxygens Sector Group, have decided to combine their knowledge and experience in order to present consistent recommendations on the bulk storage of hydrogen peroxide. The purpose of this guideline can be defined as following:

- To provide to users, authorities and other stakeholders information for carrying out risk assessments for new or existing storage installations of hydrogen peroxide. Although it is a well-known product, the existing literature on the product is wide but neither complete nor homogeneous. This guideline, as a common source of information, should minimise the risk of confusion and uncertainty among producers, users and regulators.

- To ensure the safety of the installations of producers and users of hydrogen peroxide by realistic proposals concerning the design and operation of hydrogen peroxide storage installations. This guideline should be used as a basis for training and increasing the know-how of all hydrogen peroxide users.
- To set up minimum harmonised requirements for the storage installations, accepted by all the hydrogen peroxide producers which are members of Cefic Peroxygens Sector Group.

The scope of the guideline is restricted to the following installations:

- Concentration of hydrogen peroxide up to 70%. Higher concentrations of hydrogen peroxide present other potential risks and are only used in small quantities for minor and specialised applications.
- Fixed storage installations of hydrogen peroxide. The transportation, packaging and uses of hydrogen peroxide are not covered in this guideline.

Considering the diverse nature of existing hydrogen peroxide storage installations (different concentrations of product, different size and location of the tanks), it is impossible to define fixed technical and organisational standards having to be used in all cases. Our methodology for the development of this guideline has consisted of providing a risk assessment framework and the main basic elements for:

- the design of the hydrogen peroxide storage tank and its auxiliary equipment,
  - the definition of the operating procedures related to the hydrogen peroxide storage installation,
  - the preparation of the emergency plan,
- in order to reach the best level of safety for the personnel and the environment by the introduction of best practicable means.

This guideline reflects our present best level of knowledge. It is not intended to replace the applicable regulations but is complementary to them. The common commitment of the Cefic hydrogen peroxide producers is to maintain an improved safety through the implementation of this guideline.

The companies are ready to help all stakeholders in the achievement of this objective.

# Definitions

For the purpose of this guideline, the following terms are defined below:

|                                |                                                                                                                                                                                                                                                                                                                     |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Adequate:</b>               | this term is used in the risk assessment of the chapter 3. It refers to the effectiveness of safety features in preventing harm to people and environment and material damage, given the present state of the art of the European producers.                                                                        |
| <b>Best practicable means:</b> | the techniques by which the greatest reduction of risk is obtained, taking into consideration the economic aspect.                                                                                                                                                                                                  |
| <b>Concentration:</b>          | the concentration in percent of hydrogen peroxide in this guideline always refers to weight concentration.                                                                                                                                                                                                          |
| <b>Hydrogen Peroxide:</b>      | commercial aqueous solutions of hydrogen peroxide, with a concentration up to 70%.                                                                                                                                                                                                                                  |
| <b>Incompatible material:</b>  | a material that, when in contact with hydrogen peroxide, can cause hazardous reactions such as decomposition or is itself adversely affected by contact with hydrogen peroxide.                                                                                                                                     |
| <b>Minimum requirement:</b>    | indicates that the item in question must be incorporated at every hydrogen peroxide storage installation according to the current guideline. Should technical or organisational alternative be chosen, it has to be demonstrated that it brings a comparable level of safety.                                       |
| <b>New installation:</b>       | indicates a new site that includes a hydrogen peroxide storage tank.                                                                                                                                                                                                                                                |
| <b>New storage tank:</b>       | indicates a new hydrogen peroxide storage tank, that nevertheless may be installed in an existing site, with existing constraints regarding the location which have to be taken into consideration in the study of the best practicable solution.                                                                   |
| <b>Shall/must:</b>             | indicates a mandatory requirement.                                                                                                                                                                                                                                                                                  |
| <b>Should:</b>                 | indicates a recommendation or that which is advised but not mandatory.                                                                                                                                                                                                                                              |
| <b>Storage tank:</b>           | a storage tank in this guideline refers to the fixed tank used for the storage of hydrogen peroxide as commercial solution (tank of final product for the producers, tank of raw material for the users). The storage and handling of drums or IBC (Intermediate bulk containers) is not covered in this guideline. |
| <b>Recommendation:</b>         | indicates advice, the application having to be considered in the context of each installation.                                                                                                                                                                                                                      |

# I. Properties & classification

## I. Physical data and properties

Hydrogen peroxide is a **clear, colourless liquid**. It is only use in aqueous solution and is miscible with water in all proportions.

At low concentrations, hydrogen peroxide is **odourless**. It has a slightly pungent odour at higher concentrations.

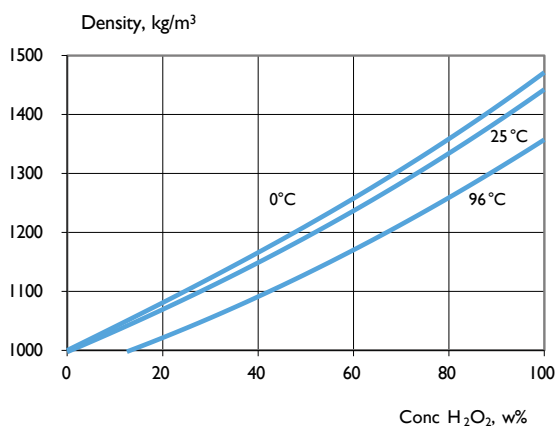
Chemical formula:  
**H<sub>2</sub>O<sub>2</sub>**.

Molecular weight:  
**34.016 g/mol**



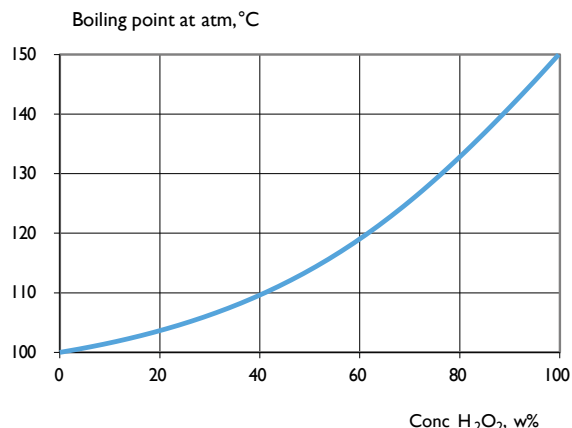
### DENSITY:

The density of hydrogen peroxide at different temperatures.



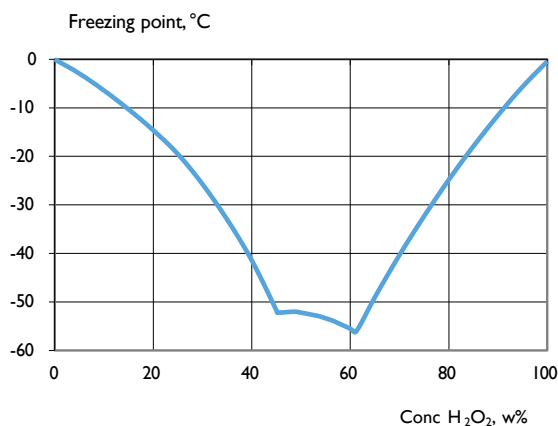
### BOILING POINT:

The boiling points of hydrogen peroxide at atmospheric pressure.

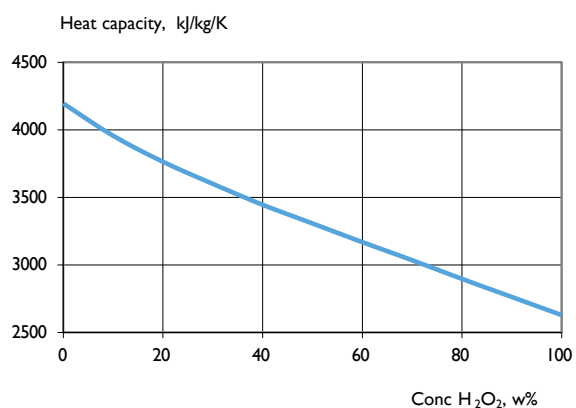


**FREEZING POINT:**

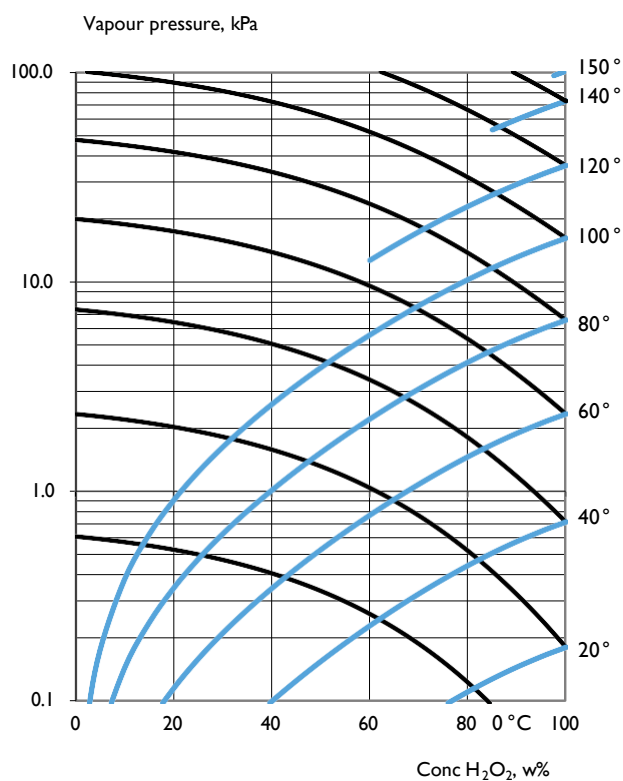
Hydrogen peroxide at various concentrations have the following freezing points.

**SPECIFIC HEAT:**

The specific heat of hydrogen peroxide at 25°C.

**VAPOUR PRESSURE:**

The total vapour pressure (black curve) over a hydrogen peroxide increases with increasing temperature and decreases with increasing hydrogen peroxide concentration. The partial pressure of hydrogen peroxide (blue curve) increases with increasing temperature and the hydrogen peroxide concentration of the solution.

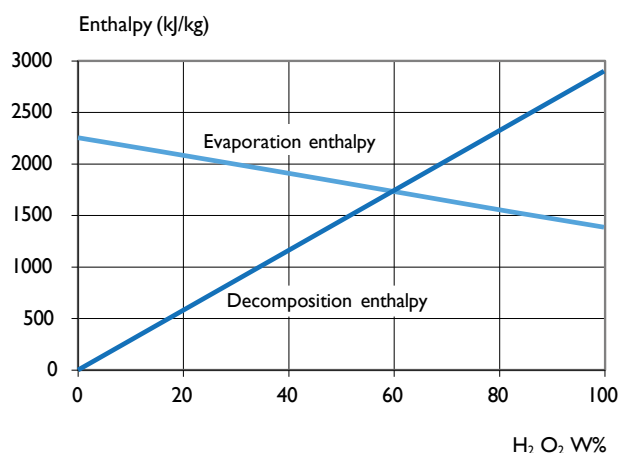




### HEAT OF EVAPORATION:

Transformation of hydrogen peroxide to vapour requires less heat at high concentrations of hydrogen peroxide.

The following diagram shows that the higher hydrogen peroxide concentration the higher decomposition enthalpy and the lower evaporation enthalpy.



**Comment:** Calculations and tests confirm that there is always a decrease of the concentration of the hydrogen peroxide in case of adiabatic decomposition, even for concentration above 64%<sup>1</sup>. Hydrogen peroxide can never be concentrated by the decomposition itself.

### PHYSICAL PROPERTIES OF TYPICAL HYDROGEN PEROXIDE:

| Concentration |  Density at 20°C |  Boiling point |  Freezing point | Viscosity at 20°C |       |
|---------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------|-------------------|-------|
| weight %      | kg/m <sup>3</sup>                                                                                   | °C                                                                                                | °C                                                                                                 | Ns/m <sup>2</sup> | cp    |
| 0 (water)     | 1000                                                                                                | 100                                                                                               | 0                                                                                                  | 0.001002          | 1.002 |
| 35            | 1132                                                                                                | 108                                                                                               | -33                                                                                                | 0.00111           | 1.11  |
| 50            | 1196                                                                                                | 114                                                                                               | -52                                                                                                | 0.00117           | 1.17  |
| 70            | 1288                                                                                                | 126                                                                                               | -40                                                                                                | 0.00124           | 1.24  |

<sup>1</sup> Test report Eka Chemicals BC 2001-116

## 1.2. Chemical data and properties

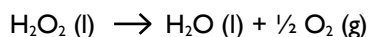
Hydrogen peroxide is a very reactive substance and can undergo different types of reactions based on the following chemical mechanisms:

- **decomposition**
- **redox reactions**
- **reactions with organic substances**

Incompatibility with substances and materials should always be assumed unless the opposite has already been proven.

### DECOMPOSITION:

In its commercial form, hydrogen peroxide is a stable compound. pH of industrial peroxide is controlled by producers in order to ensure a maximal stability of the hydrogen peroxide.



98 kJ per mol H<sub>2</sub>O<sub>2</sub>

2882 kJ/kg

Decomposition is affected by heat, pH and contamination. It occurs when hydrogen peroxide is contaminated by e.g. certain metals (carbon steel, copper...). Hydrogen peroxide forms oxygen and water upon decomposition.

The reaction generates heat, which may be substantial.

### IMPACT OF PH:

Especially increase of the pH can have a negative impact upon stability. If the pH of the hydrogen peroxide is raised, this considerably increases the rate of decomposition. This may occur when alkaline substances (e.g. caustic soda, sodium silicate, lime, hypochlorite, ammonia) are mixed with hydrogen peroxide. At the opposite, very low pH, may also increase decomposition rate.

### HOMOGENEOUS DECOMPOSITION:

Accelerated decomposition may occur when hydrogen peroxide is contaminated with incompatible soluble substances, even when the level of contamination is low (a few ppm). This is called homogeneous decomposition and occurs with a wide range of contaminants, especially salts of e.g. copper, chrome, iron, vanadium, tungsten, manganese, molybdenum and platinum.

### HETEROGENEOUS DECOMPOSITION:

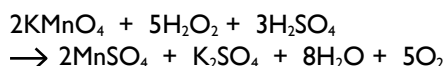
Heterogeneous decomposition is the occasionally very rapid decomposition of hydrogen peroxide which occurs when it comes into contact with insoluble material. This occurs on contact with almost all material, but the speed of the decomposition varies greatly, depending on the nature of the contaminant and its contact surface.

### REDOX REACTIONS:

Hydrogen peroxide has a high oxidation potential and acts as a powerful oxidizing agent. Hydrogen sulphide dissolved in water is oxidized, eliminating, for example, evil-smelling hydrogen sulphide from wastewater.



Under certain conditions, hydrogen peroxide may also act as a reducing agent, for example in the following reaction with potassium permanganate. The reaction may be used to determine the concentration of hydrogen peroxide.



#### REACTIONS WITH ORGANIC SUBSTANCES:

Hydrogen peroxide generally acts as oxidizing agent in degrading many organic compounds. At low concentrations, these reactions are slow and safe. Mixtures of organic solvents and hydrogen peroxide solutions containing over 40% can become explosive.

At concentrations below 30%, hydrogen peroxide can react with other chemicals to form dangerous substances, for example, organic peroxides.

## I.3. Classification and Labelling according to CLP / GHS

This is a general overview of the classification and labelling of hydrogen peroxide according to Regulation 1272/2008<sup>2</sup>. It covers all aqueous hydrogen peroxide solutions manufactured by the members of the CEFIC Peroxygens Sector Group.

|                |                           |                                                                    |                                                                                       |
|----------------|---------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>C ≥ 70%</b> | <b>Ox. Liq. 1:</b>        | <b>H271</b><br>(May cause fire or explosion; strong oxidiser)      |  |
|                | <b>Acute Tox. 4:</b>      | <b>H302</b><br>(Harmful if swallowed)                              |                                                                                       |
|                | <b>Acute Tox. 4:</b>      | <b>H332</b><br>(Harmful if inhaled)                                |                                                                                       |
|                | <b>Skin Corr. 1A:</b>     | <b>H314</b><br>(Causes severe skin burns and eye damage)           |                                                                                       |
|                | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         |                                                                                       |
|                | <b>STOT SE 3:</b>         | <b>H335</b><br>(May cause respiratory irritation)                  |                                                                                       |
|                | <b>Aquatic acute 1:</b>   | <b>H400</b><br>(Very toxic to aquatic life)                        |                                                                                       |
|                | <b>Aquatic chronic 3:</b> | <b>H412</b><br>(Harmful to aquatic life with long lasting effects) |                                                                                       |
|                |                           |                                                                    | <b>Danger</b>                                                                         |

<sup>2</sup> Peroxygens SG, Hydrogen Peroxide Classification and Labelling, August 2015

|               |                           |                                                                    |                                                                                                                                                                                                                                                                                                                                                                           |
|---------------|---------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 50% ≤ C < 70% | <b>Ox. Liq. 2:</b>        | <b>H2712</b><br>(May cause fire or explosion; strong oxidiser)     | <br><br><br><br><b>Danger</b> |
|               | <b>Acute Tox. 4:</b>      | <b>H302</b><br>(Harmful if swallowed)                              |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Acute Tox. 4:</b>      | <b>H332</b><br>(Harmful if inhaled)                                |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Skin Corr. 1A:</b>     | <b>H314</b><br>(Causes severe skin burns and eye damage)           |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>STOT SE 3:</b>         | <b>H335</b><br>(May cause respiratory irritation)                  |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Aquatic acute 1:</b>   | <b>H400</b><br>(Very toxic to aquatic life)                        |                                                                                                                                                                                                                                                                                                                                                                           |
| 35% ≤ C < 50% | <b>Aquatic chronic 3:</b> | <b>H412</b><br>(Harmful to aquatic life with long lasting effects) | <br><br><br><b>Danger</b>                                                                                  |
|               | <b>Acute Tox. 4:</b>      | <b>H302</b><br>(Harmful if swallowed)                              |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Acute Tox. 4:</b>      | <b>H332</b><br>(Harmful if inhaled)                                |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Skin Irrit. 2:</b>     | <b>H315</b><br>(Causes skin irritation)                            |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>STOT SE 3:</b>         | <b>H335</b><br>(May cause respiratory irritation)                  |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Aquatic acute 1:</b>   | <b>H400</b><br>(Very toxic to aquatic life)                        |                                                                                                                                                                                                                                                                                                                                                                           |
| 30% ≤ C < 35% | <b>Aquatic chronic 3:</b> | <b>H412</b><br>(Harmful to aquatic life with long lasting effects) | <br><br><br><b>Danger</b>                                                                                  |
|               | <b>Acute Tox. 4:</b>      | <b>H302</b><br>(Harmful if swallowed)                              |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Acute Tox. 4:</b>      | <b>H332</b><br>(Harmful if inhaled)                                |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Aquatic acute 1:</b>   | <b>H400</b><br>(Very toxic to aquatic life)                        |                                                                                                                                                                                                                                                                                                                                                                           |
|               | <b>Aquatic chronic 3:</b> | <b>H412</b><br>(Harmful to aquatic life with long lasting effects) |                                                                                                                                                                                                                                                                                                                                                                           |

|               |                           |                                                                    |                                                                                                         |
|---------------|---------------------------|--------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 25% ≤ C < 30% | <b>Acute Tox. 4:</b>      | <b>H302</b><br>(Harmful if swallowed)                              |                      |
|               | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         |                      |
|               | <b>Aquatic acute 1:</b>   | <b>H400</b><br>(Very toxic to aquatic life)                        |                      |
|               | <b>Aquatic chronic 3:</b> | <b>H412</b><br>(Harmful to aquatic life with long lasting effects) | <b>Danger</b>                                                                                           |
| 22% ≤ C < 25% | <b>Acute Tox. 4:</b>      | <b>H302</b><br>(Harmful if swallowed)                              |                      |
|               | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         | <br><b>Danger</b>    |
| 8% ≤ C < 22%  | <b>Eye Dam. 1:</b>        | <b>H318</b><br>(Causes serious eye damage)                         | <br><b>Danger</b>   |
| 5% ≤ C < 8%   | <b>Eye Irrit. 2:</b>      | <b>H319</b><br>(Causes serious eye irritation)                     | <br><b>Warning</b> |
| C < 5%        | <b>Not Hazardous</b>      |                                                                    |                                                                                                         |

**Remark:** According to CLP Regulation, precautionary statements shall be selected in accordance with the criteria laid down in Part I of Annex IV taking into account the hazard statements and the intended or identified use or uses of the substance or mixture. Precautionary statements are therefore not harmonised.

**Note:** For specific information regarding labelling and classification always refer to the supplier's Safety Data Sheet.

## 2. Hazards & consequences assessment

### 1. Hazards

The potential hazards associated with a peroxide storage installation may be classified as follows :

- |                                                                                                                                                                                                                                |                                                                                                                                                                                            |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>▪ <b>Decomposition</b>, leading to:<ul style="list-style-type: none"><li>• vapour release</li><li>• pressure burst (if venting is inadequate)</li><li>• heat release</li></ul></li></ul> | <ul style="list-style-type: none"><li>▪ <b>Loss of containment</b>, leading to:<ul style="list-style-type: none"><li>• fire</li><li>• environmental and health hazards</li></ul></li></ul> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Both vapour and condensed phase explosion hazards associated with hydrogen peroxide alone (not contaminated by organic materials) do not have to be considered in the case of bulk storage of usual concentrations below 70 %.

#### 2.1.1 DECOMPOSITION

There is always with hydrogen peroxide a so-called natural decomposition which is easy to handle (the product must never be stored in a totally closed environment).

Considering a tank submitted to a higher rate of decomposition, it will release and disperse oxygen, steam and hydrogen peroxide fumes. The rate of release is variable, depending on the prevailing decomposition or boil up rate while the total quantity released is depending on the initial inventory and hydrogen peroxide concentration.

Decomposition may be initiated by an increase of temperature due to an external heat source ([see chapter 2.1.3](#)) or by catalytic contaminants such as transition metal ions, strong acids or bases.

A convenient method of classifying all potential sources of contaminants is to assign each to a level of catalytic activity, representing a decomposition rate increase of say 100, 1000, 10000 times the normal. The effect of particular contaminants can vary enormously depending on their nature and amount, the stabilisation of the product and other factors. Some typical values are shown in [appendix 1](#) (experimental results with

addition of iron or caustic soda). Based on experience, the contamination with alkaline products represents the most critical scenario of decomposition to be considered for hydrogen peroxide storage tanks.

In order to obtain rate increases of 100 times or greater, it is necessary for the peroxide solution to become grossly contaminated which should not normally be possible in a well maintained storage. In such a case, any increase in the rate is expected to come from a natural build up of metal ions due to corrosion/erosion (especially in small tanks) or by the loss of the effectiveness of the stabilisers. In these circumstances, the increase in rate will typically range from 10 to 100 times the normal. This suggests a 100 fold increase in the rate is a realistic maximum for catalytically induced decomposition and a value of 1000 probably representing a conservative value for the design of the safety vent. In case of extreme contamination (e.g. alkaline), a higher rate can be anticipated.

A progressive decomposition may lead to safe venting of the resulting gas and vapour, or a pressure burst of the vessel if the vent is not adequate. In the case of the former, the only consequence will be that arising from a harmful peroxide vapour emission and the subsequent risk of exposure. In the event of a pressure burst, there could be additional effects due to blast, missiles or hot liquid ejection.

### 2.1.2 LOSS OF CONTAINMENT



#### Fire hazard:

Hydrogen peroxide and its oxidising properties could cause fire in the presence of organic substances (oil, grease, dust...) or other combustible materials (wood, paper, textiles, leather, ...). In the presence of hydrogen peroxide, the intensity of a resulting fire will be greatly enhanced. Be aware that fire may not start immediately due to the slow temperature increase but can occur after a delay.



#### Health hazard:

Hydrogen peroxide poses risks to human health. It is irritant to the eyes and skin at concentrations above 5% and causes burns above 20%. In the event that hydrogen peroxide is swallowed, it can be harmful with increasing risk of serious injury or fatality with increasing concentration.

Hydrogen peroxide is not classified as a carcinogen.

Inhalation of the vapour or mist will cause extreme internal irritation.

Occupational exposure limits :

- Time Weighted Average (8-hour):  
1 ppm (1.4 mg/m<sup>3</sup>),
- Short Term Exposure Limit (15 min): 2 ppm (3 mg/m<sup>3</sup>),
- Immediately dangerous to life or health concentration (IDLH): 75 ppm (105 mg/m<sup>3</sup>)<sup>3</sup>.



#### Environment hazard:

Hydrogen peroxide occurs naturally in the environment at levels of 0.1 – 4 ppb (air) and 0.001 – 0.1 mg/l (water).



#### Air:

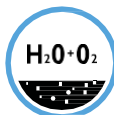
There is no regulatory limit industrial emission to air.



#### Water:

Hydrogen peroxide is a substance which can be rapidly degraded but also has the potential to kill microorganisms and higher species.

NOEC to < 1mg/L triggers Aquatic Environmental tox label (H400, H412) > 25%



#### Soil:

Hydrogen peroxide decomposes readily to form water and oxygen

<sup>3</sup> The National Institute for Occupational Safety and Health (NIOSH) value: <https://www.cdc.gov/niosh/idlh/intridl4.html>

<sup>4</sup> Chemical safety report, Hydrogen Peroxide Reach dossier

### 2.1.3 EXTERNAL FIRE, VAPOUR AND CONDENSED PHASE EXPLOSION

These scenarios are not considered later in the guideline for the following reasons:

Vapour or condensed phase explosion of hydrogen peroxide itself is highly improbable for concentrations below 74%: it is therefore excluded from this guideline.

For other explosion scenarios, a precondition is the presence of organic material in the hydrogen peroxide installation. This precondition is generally avoided by the design and operating practices of an hydrogen peroxide installation. In particular, there is a strong focus on the avoidance of all contamination and incompatible materials including organic materials.

In principle, a mixture of hydrogen peroxide and organics can lead to a condensed phase explosion for hydrogen peroxide concentrations over 40% and under special conditions (miscibility, concentration and dispersion of the organics). Such an explosion releases an enormous quantity of energy (detonation), so that no safety relief equipment could prevent a burst of the

tank. For plants having to deal with this risk, special emphasis on prevention must absolutely avoid organic contamination. The following requirements apply in such a case:

- segregation from organic materials for storage and drainage,
- procedures should be established that exclude absolutely the possibility of unloading an organic material in an hydrogen peroxide tank, and vice versa (separated lines, double locked system, procedure of access control).

For fire, the effects on hydrogen peroxide are likely to be minimal; the worst being a remote chance of bursting a pipe. Only small tanks (and especially plastic tanks) could be affected within a reasonable timescale; a specific protection of the tank should be studied in such a case. Bigger metallic tanks (> 50 m<sup>3</sup>) can stand a fire for several hours because of the small exposed surface area/mass unit (past incident experience is consistent with this view).

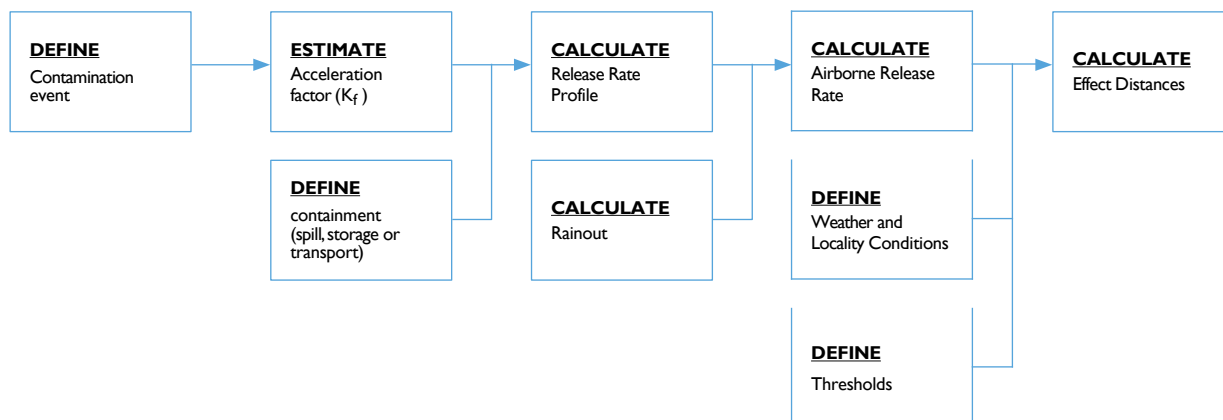
## 2. Assessment of Probable Consequences

### 1. DECOMPOSITION

#### Release and dispersion:

One of the consequences of a peroxide decomposition is the release of potentially harmful vapours into the atmosphere. It is therefore necessary to determine dispersion characteristics so that the ground level concentrations can be estimated and compared with the maximum allowable for exposure to give a contour of affected distances.

The following is an overview of the process:



$K_f$  is an acceleration factor which relates the rate of decomposition of a contaminated product to an uncontaminated product ( $K_f = 1$ : see [Appendix I](#)). Indicative  $K_f$  values are as follows:

| Acceleration Factor ( $K_f$ ) | Contamination Level                                     |
|-------------------------------|---------------------------------------------------------|
| 1                             | Reference stability                                     |
| 1 to 10                       | Acceptable Product                                      |
| 10 - 100                      | Minor metallic contamination or insufficient stabilizer |
| 100 - 1000                    | Larger metallic contamination                           |
| 1000 and beyond               | Alkali or gross metallic contamination                  |

Various containment scenarios can be envisaged, such as decomposition in:

- an atmospheric pressure storage tank with a properly sized vent;
- a transport ISO container;
- a bunded area or spillage

In the case of tanks and ISO containers, the source term should be the maximum flow that will not break the tank or container, on the basis this would give the highest source term.

| Examples of weather and locality conditions that could be used are: |                                       |
|---------------------------------------------------------------------|---------------------------------------|
| D5:                                                                 | Wind speed 5 m/s, stability class "D" |
| F2:                                                                 | Wind speed 2 m/s, stability class "F" |
| Ambient temperature:                                                | 20 °C                                 |
| Relative humidity:                                                  | 75 %                                  |
| Terrain (Surface Roughness):                                        | Rural and Urban                       |

As an example of information that could be used for thresholds which are relevant for emergency situations here are two references that may be suitable:

1. American Conference of Governmental Industrial Hygienists (ACGIH): Emergency Response Planning Guidelines (ERPG)

2. UK HSE: Specified level of toxicity (SLOT), Significant likelihood of death (SLOD)

|                   |                                                                                                                                                                                                                                                                                           |      |        |              |
|-------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|--------|--------------|
| ERPG-1<br>(ACGIH) | "... is the maximum airborne concentration below which <b>nearly all individuals</b> could be exposed for up to 1 hour without experiencing more than mild, transient adverse health effects or without perceiving a clearly defined objectionable odour."                                | 1 hr | 10     | ppm          |
| ERPG-2<br>(ACGIH) | "... is the maximum airborne concentration below which <b>nearly all individuals</b> could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action." | 1 hr | 50     | ppm          |
| ERPG-3<br>(ACGIH) | "... is the maximum airborne concentration below which <b>nearly all individuals</b> could be exposed for up to 1 hour without experiencing or developing life-threatening health effects."                                                                                               | 1 hr | 100    | ppm          |
| SLOT<br>(UK HSE)  | Severe distress to almost everyone<br>Substantial fraction of exposed population requiring effect of medial attention<br>Some people seriously injured, requiring prolonged medical attention.<br>Highly susceptible people possibly being killed                                         | -    | 86000  | ppm * minute |
| SLOD<br>(UK HSE)  | 50% Mortality of an exposed population                                                                                                                                                                                                                                                    | -    | 344000 | ppm * minute |

For a decomposition initiated by fire exposure, the rate of vapour evolution is relatively low and may be assumed to be dominated by the selected decomposition case.

**Pressure burst:**

Storage tanks must be provided with emergency relief vent designed to relieve at low pressure. In the event of a substantial decomposition, overpressurisation may occur leading to bursting of the vessel at or around its yield pressures. In these circumstances damage could result from air blast and emission of hot reaction products.

**Air blast:**

In the event of an overpressure, a proportion of the released energy is always utilised to create the blast. This proportion is difficult to set because of different failure modes. In the absence of information on failure modes, no serious error is introduced if a value in the middle of the range is assumed (say 50%).

A method of estimating blast damage relies on the concept of TNT equivalence. Blast damage has to be considered in the immediate vicinity of an explosion and is usually weak (window breakage, light inner wall rupture,...) below the overpressure circle of 50 mbar. Missile effects beyond this overpressure limit have a low probability of occurrence. See example of calculation in appendix 3.

**Liquid ejection:**

It is not possible to quantify effects which may result from hot liquid/vapour ejection with any order of accuracy. However, it is not expected that these effects can extend to very great distances. Incident experience is consistent with this view.

**2.2.2 LOSS OF CONTAINMENT****Fire:**

If a fire occurs together with a leakage of hydrogen peroxide, the hydrogen peroxide decomposition and oxygen production will increase the intensity in burning. This increase will be translated into a greater fire growth and higher flame temperatures than if there were no oxidant present. An acceptable compromise for the estimation of this effect would be:

- a 50% increase in the flame height
- an increase of up to 100% in the surface emissive power of the flame to a maximum of ~250 kW/m<sup>2</sup>.

**Contact with human:**

Damage to the eyes, skin in case of external contact; damage to bronchia in case of inhalation. This damage might be irreversible or even fatal.

**Environment:**

Can cause short term damage. However, hydrogen peroxide is not persistent and the environment can fully recover.

## 3. General Guidelines for Storage

The purpose of this guideline is to act as a reference source for informing all concerned on how to achieve an acceptable level of risk from bulk hydrogen peroxide storage operations. The first step is to set the overall risk management framework.

For each of the major hazard scenarios (accelerated decomposition and loss of containment), there are in principle two stages during which damage to people, environment and material can be avoided. These stages are prevention, and control/damage limitation (C/DL).

The guiding principle - according to experience - is that, although the many elements of prevention are always necessary, they may not always be sufficient (a single defect in one element can be enough to initiate an incident). Therefore, for the overall level of risk to be acceptable, there must be additional effective C/DL measures.

In order to specify the extent of additional C/DL measures required, it is first necessary to explain the risk categorisation philosophy upon which this guideline is based.

Three categories are identified as follows:

- **Preferable:** This is the highest standard and is expected to result in the lowest risk. It should be considered as the specific target for new designs.
- **Acceptable:** This standard, whilst not as high as the above, is accepted for existing installations.
- **Unacceptable:** This standard represents an unacceptable risk to man and/or the environment and improvements have to be made.

In the following sections, both main hazards are considered in turn and in each case, the available combinations of control/damage limitation measures are categorised as preferred, acceptable or unacceptable.

## 3.1 Hazards

### 1. RUNAWAY DECOMPOSITION

This event can occur if the rate of hydrogen peroxide decomposition is increased due to catalytic impurities. There are many possible sources and they must all be excluded for prevention to be successful. Common examples are:

- inappropriate materials of construction (vessel, pipework, fittings, equipment components...)
- ineffectively passivated material of construction
- external contamination (airborne, maintenance, cross contamination, misdirected chemical delivery)

The following table sets the standards for control/damage limitation measures. It is derived from an assessment of the risk of human injury resulting from either the bursting of inadequately vented equipment or exposure to vapour/liquid emanating from a runaway decomposition. Definition of adequate venting, separation and detection is given in chapters 4 and 5 and [appendix 4](#). A local supply of water for first aid and spill dilution is always compulsory.

| Adequately vented             | Adequate location and separation | Detection and Temperature alarm | Status                                             | Comments                                         |
|-------------------------------|----------------------------------|---------------------------------|----------------------------------------------------|--------------------------------------------------|
| <b>New installations</b>      |                                  |                                 |                                                    |                                                  |
| Yes                           | Yes                              | Yes                             | Standard                                           |                                                  |
| <b>Existing installations</b> |                                  |                                 |                                                    |                                                  |
| Yes                           | Yes                              | No                              | Acceptable only for small tanks <60 m <sup>3</sup> | Danger limited if product remains in the storage |
| Yes                           | No                               | Yes                             | Acceptable                                         |                                                  |
| No                            | Yes                              | Yes                             | Acceptable                                         |                                                  |
| No                            | No                               | Yes                             | Unacceptable                                       |                                                  |
| Yes                           | No                               | No                              | Unacceptable                                       |                                                  |
| No                            | No                               | No                              | Unacceptable                                       |                                                  |
| No                            | Yes                              | No                              | Unacceptable                                       |                                                  |

## 2. LOSS OF CONTAINMENT

As with runaway decomposition, this event can be realised in many ways, all of whose prevention must be practised. Common examples are:

- overflow
- defective gaskets
- human error (e.g. valve alignment/flange tightening)
- mechanical failure e.g. hoses, connections
- pump seal failure
- pressure relief

Later chapters detail the prevention measures. However, standards for control and damage limitation are according to the following table, which is derived from an assessment of risk of damage to people and environment in the event of a significant loss of containment.

Clarification of adequate containment, location, separation and detection is given in chapters 4 and 5.

| Adequate containment          | Adequate location and separation | Detection and level alarm | Status                                       | Comments                                                                                                           |
|-------------------------------|----------------------------------|---------------------------|----------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| <b>New installations</b>      |                                  |                           |                                              |                                                                                                                    |
| Yes                           | Yes                              | Yes                       | Standard                                     |                                                                                                                    |
| <b>Existing installations</b> |                                  |                           |                                              |                                                                                                                    |
| Yes                           | Yes                              | No                        | Acceptable                                   | Emergency response plan needed                                                                                     |
| Yes                           | No                               | Yes                       | Acceptable                                   |                                                                                                                    |
| No                            | Yes                              | Yes                       | Acceptable                                   |                                                                                                                    |
| Yes                           | No                               | No                        | Unacceptable except under special conditions | High integrity emergency procedure required and no nearby combustible inventory                                    |
| No                            | No                               | Yes                       | Unacceptable except under special conditions | A partial containment is indispensable. The reliability of the detection/alarm and emergency plan has to be proved |
| No                            | Yes                              | No                        | Unacceptable                                 |                                                                                                                    |

## 3.2 Prevention of incidents

The most important elements of incident prevention are as follows:

- The avoidance of all contamination.
- The dedication of equipment to hydrogen peroxide and avoidance of cross contamination by high integrity isolation from other chemicals and utilities.
- All equipment and fittings to be constructed from materials which are specifically approved and prepared for hydrogen peroxide use.
- Equipment design standards to provide a high degree of mechanical integrity.
- All equipment to be provided with appropriate vents.
- Avoidance of contact with incompatible materials.
- Written unloading, operation, maintenance and management of change procedures
- Display of unloading procedure and labelling at the unloading station

## 3.3 Detection and reduction of effects

The first step to reduce the effects of an incident is generally to **detect any deviation** as soon as possible:

- measurement of the temperature of the storage, together with an alarm when it increases.
- level indication and/or high-level alarm on the tank, liquid detection,
- regular inspection and control of the storage facility, including alarms and interlocks systems

The following features will **reduce the effect** of an incident:

- Adequate venting of the storage tank and its accessories,
- Safety shower and eyebath in the vicinity,
- Use of personal protective equipment,
- Location on a concrete surface provided with a retention basin,
- Safety distances between the storage tank and adjacent buildings,
- Supply of water for dilution of any spillage,
- Pre-planning of emergency response, together with appropriate training and practise exercises.
- Display of the emergency response instructions

## 4. Hydrogen peroxide storage tank

Minimum requirements and recommendations concerning the design and the construction of hydrogen peroxide storage tanks are presented in this chapter. The diagram ([page 29](#)) representing a storage tank installation of hydrogen peroxide presents essential items of equipment and, in addition, some optional features. The minimum requirements shall be installed in new storage tank installations and shall be considered for the evaluation and upgrade of existing storage tanks. The choice of the optional features should be considered in each individual case taking into account the local conditions.

Only atmospheric tanks should be used for hydrogen peroxide. The tank can be either horizontal or vertical. It is essential that the tanks are built only by firms which are able to meet the highly specific requirements for producing compatible high integrity tanks and fittings. All hydrogen peroxide tanks shall be of a mechanical quality and condition appropriate for storing hazardous chemicals. In any case, the design of the storage tank installation should be done together with a hydrogen peroxide producer.

### 1. Temperature control

Temperature is the best parameter for the detection and analysis of the evolution of the situation in case of decomposition of hydrogen peroxide. For this reason, this parameter shall be measured permanently, to set adequate alarm and to monitor the evolution of the temperature in case of detected deviation (detection and alarm in reference to the [chapter 3.1.1, runaway decomposition](#)).

The homogeneity of the liquid phase cannot be guaranteed (principally in the case of heterogeneous decomposition). We have to recognise that the measured temperature will not necessarily be representative of the whole content of the tank. Therefore, it may be necessary, according to the size of the vessel, to install more than one temperature gauge. In order to get an adequate detection system, the recommendation for the number of temperature gauges is:

- 1 - if  $V < 100 \text{ m}^3$ ,
- 2 - if  $100 \text{ m}^3 < V < 500 \text{ m}^3$ ,
- 3 - if  $500 \text{ m}^3 < V < 1000 \text{ m}^3$ ,
- 4 - if  $V > 1000 \text{ m}^3$ .

Since the surface of the liquid should have the highest temperature, an alternative technology consists in measuring the surface temperature (through infrared for instance); the number of measurement cells can be reduced to one or two, even in the case of big storage tanks.

**Alarm:** the decomposition rate increases with the temperature, the alarm should therefore be set as low as possible, in accordance with the local conditions. The first monitoring alarm can be set 5°C above the maximum normal liquid temperature; the safety alarm a further 5°C higher (refer to [chapter 8](#)). Alternatively, the variation of the temperature of the liquid can be considered for the evaluation of a decomposition situation with the recommended alarm value of +2°C/h. Those recommendations are consistent with the emergency response presented in [chapter 8](#).

For example, apply the following parameters, to be readjusted according to the site's own experience (hypothesis of the summer conditions with storage maximum temperature  $T_{\text{max}} = 40^\circ\text{C}$ )

Alarms in the liquid phases only:

- Monitoring alarm at 45°C, i.e.  $T_{\text{max}} + 5^\circ\text{C}$
- Safety alarm at 50°C, i.e.  $T_{\text{max}} + 10^\circ\text{C}$
- Alarm on temperature increase at  $dT/dt > 2^\circ\text{C/h}$

Alarm switches and thermocouples must not be of the mercury type, and the fluid used in the thermocouple well should be compatible with hydrogen peroxide (no oil).

## 4.2 Emergency relief vent

The storage tank **must have an unobstructed emergency vent (minimum requirement)** to provide relief in case of decomposition. The best way is to install a loose manhole cover assembly that opens freely at low overpressure. It is desirable that the manholes are fitted with a loose wire mesh cover of appropriate material of construction to prevent large objects such as inspection torches, safety helmets, pens or tools falling into the tank.

The sizing of this emergency vent requires information on the worst decomposition scenario to be taken into account. The following cases must be considered for the evaluation of the adequacy of the venting system (in reference to the [chapter 3.1.1, runaway decomposition](#)) :

- **Case A:** the contamination of the tank with strong decomposition catalyst, typically alkaline products (e.g. caustic soda) can't be excluded. The safety vent has to be as big as technically possible: 50% opening roof with weak seam.
- **Case B:** the above case is excluded but the contamination of the tank with other decomposition substances has to be considered. A totally empirical approach, based on the analysis of past incidents, leads to a value of **200 cm<sup>2</sup> / t H<sub>2</sub>O<sub>2</sub> 100%**  
This value, independent of the hydrogen peroxide concentration, is commonly used for the design of the relief vent by the users of hydrogen peroxide.
- **Case C:** the storage tanks are located in highly controlled areas, where the organisation and the design of the plant reduces considerably the probability and the severity of a contamination (storage plant dedicated to hydrogen peroxide for instance). A theoretical approach can be developed

in those defined cases by the definition of the worst contamination scenario, taking into consideration:

- the concentration of the stored product,
- the volume of the storage,
- the decomposition kinetic, based on the evaluation of the acceleration of the decomposition induced by the contaminants by laboratory tests.

Examples of this approach are presented in [appendix 4](#).

In all cases, the design of the emergency relief vent should be developed together with a hydrogen peroxide producer.

In order to minimise the consequence of tank burst, it is recommended to ensure the rupture at the top of the tank at as low a pressure as possible. One option is to ensure the frangibility of the roof (weak welding seam). In case of severe overpressure not contained in spite of the relief vent (a two-phases flow through the venting area in case of intensive decomposition is a factor of uncertainty in the design of the vent), the roof would open and act as safety vent, preventing any explosion of the tank.

In the case of existing installations where these design rules could not be adapted, it is necessary during the risk analysis that extra emphasis is placed on detection measures and emergency procedures (e.g. flooding or dumping).

It must not be assumed that a vent designed with the above method is a guarantee of safety: it is a recommendation which is intended to be used in conjunction with other preventive and emergency measures and not instead of them.

## 4.3 Detection of a loss of containment

Hydrogen peroxide is not corrosive towards those appropriate materials of construction described in this guideline. For this reason, the probability of a leakage resulting from a corrosion of fixed pipes and connections is very low: a visual and regular

inspection of the plant should be sufficient. Plastic installation should be inspected with care because of the risk of embrittlement. An overflow of the tank is much more likely to create a severe loss of containment.

**Level indicator / high level alarm:**

To detect any overflow of the tank, a high level alarm should be installed: this alarm can be simply a level switch. It may automatically interrupt the filling of the tank in order to prevent any overflow.

A level indicator with high and low alarm shall be installed to enable the monitoring of the peroxide inventory. Standard technology of measurement can be used, e.g. DP cell, float, radar or ultrasonic sensors (as long as **all** the materials of construction adopted are compatible with hydrogen peroxide).

If the risk of overflow can't be excluded, it must be ensured that it does not represent any risk for the personnel and the environment: the overflow pipe must be directed into a safe location (e.g. catch bund).

**Liquid detection:**

In order to exclude any uncontrolled pollution of the environment with hydrogen peroxide, liquid detection can in some cases be necessary to warn the operating personnel and to enable timely corrective actions (for instance in case of inadequate or small catch bund). Standard technology of liquid detection can be used (e.g. vibration limit switch).

## 4.4 Containment

The tank should be erected on a concrete surface. To avoid any contamination of the environment following a leakage, the storage area should be provided with a retention bund. The adequate capacity of this bund

should be defined according to the local regulation; it should at least contain 110% of the capacity of the biggest tank (if several tanks are located on the same area).

## 4.5 Materials

The selection of materials of construction to be used in service with hydrogen peroxide must be undertaken with care, otherwise decomposition problems will be encountered. A list of accepted materials of construction (including use limitations) is presented in detail in [appendix 5](#). It must be assumed that any material not listed is incompatible with hydrogen peroxide and shall not be used unless compatibility tests have been performed with the assistance of a hydrogen peroxide producer.

The following materials are commonly used for the storage of hydrogen peroxide:

**Stainless steel:**

Fully austenitic stainless steel is commonly used. The preferred grades are 304L or 316L. The welding quality is important; it should be done by inert gas shielded processes, in order to avoid impressing impurities into the metal. A special care is needed with the finishing and treatment of surfaces, including pickling and passivation (see [appendix 6](#)).

**Aluminium and its alloys:**

High purity grades of aluminium (99.5 %) and the alloy Al-Mg3 may be used, but the fabrication with those materials is more difficult than with stainless steel. For fabrication work, argon shielded arc welding methods are used with rods of parent metal, with care taken to avoid impressing impurities into the soft metal. The tank shall be passivated before use.

**Plastic material:**

Some plastic may be used for small tanks (preferably up to 50 m<sup>3</sup>) and for concentrations of hydrogen peroxide up to 60% weight. They must be very carefully selected and maintained. The mutual compatibility of the plastic and hydrogen peroxide must have been demonstrated and the safe lifespan established. High density polyethylene is preferred for the tank. Particular care should be taken when using such materials as they are liable to degrade with time and are easily damaged in case of collision. They shall not contain any pigments, mineral fillers or catalytic residues incompatible with hydrogen peroxide. If exposed to sunlight, they should contain suitable level of antioxidants and compatible UV stabilisers (consult a hydrogen peroxide producer).

## 4.6 Ancillaries

### Breathing vent:

A breathing vent must be installed in order to prevent any over- or under-pressure (minimum requirement). The design of this vent should take into consideration the risk of contamination of the tank with particles present in the air (if any). A suitable strainer/mesh must be installed.

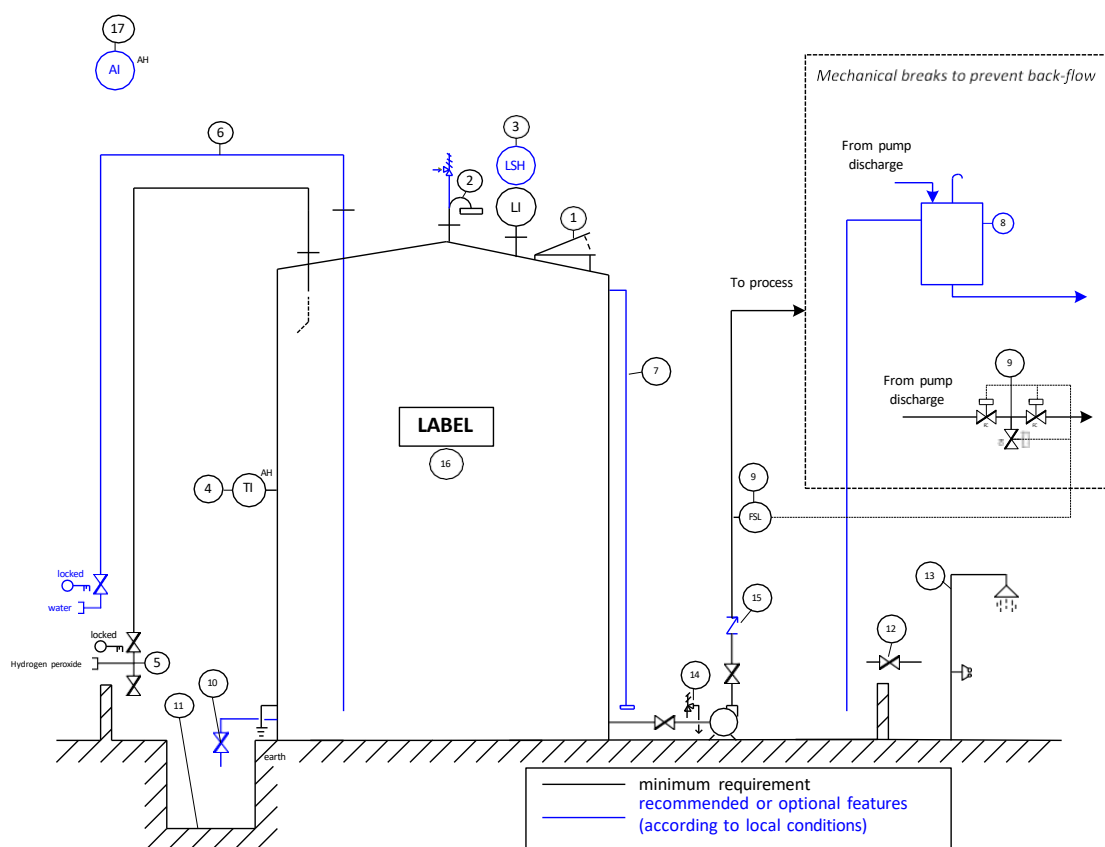
### Emergency discharge (optional):

In the strategy of protection of the tank against overpressure, an approach can consist in emptying the tank into the retention bund. This emergency discharge should be sized to prevent a bursting of the tank (in relation to the size of the relief vent) and must be operable from a safe place.

### Water source for cooling or flooding (optional):

A water source can be provided for safety reasons for cooling and flooding the tank in case of decomposition. The water flow-rate is dependent on the size of the tank and on the other protection devices (relief vent and emergency discharge). Deionised or potable water are preferred, but industrial water is acceptable. The water must be fed at the top of the tank, through a dip pipe (for mixing purpose). This pipe must in normal position be disconnected from the water feeding network (prevent contamination); the connection must be locked. It must be operated from a safe location.

TYPICAL FEATURES FOR A HYDROGEN PEROXIDE STORAGE TANK



- |   |                                                           |    |                                                                                                             |
|---|-----------------------------------------------------------|----|-------------------------------------------------------------------------------------------------------------|
| 1 | Manhole - Emergency vent                                  | 10 | Emergency discharge/ drain valve                                                                            |
| 2 | Breathing vent with strainer/mesh (+ vacuum relief valve) | 11 | Bund                                                                                                        |
| 3 | Level indicator with alarm (level interlock)              | 12 | Water for spillage dilution                                                                                 |
| 4 | Temperature indicator with alarm                          | 13 | Safety shower and eye bath                                                                                  |
| 5 | Filling connection (with locked valve or cap*)            | 14 | Safety valve (for all possibly trapped section)                                                             |
| 6 | Water for flooding (with locked valve or cap*)            | 15 | Check valve                                                                                                 |
| 7 | Overflow pipe with strainer/mesh to prevent pollution     | 16 | Label (Tank, pipes and connection)                                                                          |
| 8 | Intermediate tank (with overflow and adequate venting)    | 17 | If location in confine area, addition of an H <sub>2</sub> O <sub>2</sub> vapour analyser and light or horn |
| 9 | Low flow switch/ Block and bleed system (preferred)       |    |                                                                                                             |

(\*) cap with relief system or hole

# 5. Safety distances

## 1. Location

Storage tanks should be preferably placed outdoors, away from heat sources and combustible materials. Tank location with respect to other tanks and equipment containing other chemicals must be considered carefully.

The tank and its accessories should be located preferably in a secured zone, only accessible to authorised personnel.

Piping and pumps should be located in readily accessible areas, but where they will not be easily damaged and where any leaking hydrogen peroxide solution from a damaged line or flange will not fall on combustible materials or working areas.

Underground storage tanks should not be used. Indoors tanks or tanks on elevated floors are not recommended. In the case of indoors tanks, special attention during risk assessment should be considered. Aspects to be resolved are:

- vapour release, ventilation, evacuation and oxygen accumulation in case of decomposition.

- fire risks and drainage problems during loss of containment
- emergency relief venting to outside safe position
- emergency exits.

Tanks on elevated floors in existing installations are only acceptable if bunded and leakage control properly arranged.

When several hydrogen peroxide tanks are in the same storage area or retention basin, their separation distances should enable to carry out all emergency actions and maintenance work to be performed correctly.

Hydrogen peroxide loading/unloading stations should be equipped with the adequate protection system to prevent mechanical damages of the storage tanks by transport vehicles. The loading/unloading station should preferably be isolated from other chemicals.

## 5.2 Safety distances

The determination of safety distances between atmospheric hydrogen peroxide bulk storage tanks and objects for protection should proceed by risk evaluation and be judged in each individual case. As worst-case scenarios, pressure burst of a tank and dispersion of hydrogen peroxide droplets and vapour in decomposition situations should be considered.

This chapter aims to give all necessary information in order to proceed to the risk evaluation:

- **Fire:** as mentioned in the [chapter 2](#), the hazard related to an external fire should only be considered in the case of small storage tanks. We recommend a distance of 7.5 meters between hydrogen peroxide and combustible materials<sup>5</sup>. This distance refers to the risk of fire of the combustible materials. A non-combustible wall may be located adjacent to storage tank as an alternative to the safety distance.

- **Pressure burst of a tank:** in case of inadequate venting, decomposition of hydrogen peroxide could lead to a pressure burst of the tank. The overpressure wave generated by this burst may represent a risk for the personnel and the neighbour installation (domino effect). An example of calculation of this overpressure as a function of the distance to the tank is presented in [appendix 3](#). Both chosen limits, 140 and 50 mbar, are considered in our approach as hazard limits for the equipment/buildings and for human beings. The calculation of the distances related to those overpressure values in each individual case should help to determine:

- the risk to the neighbouring installation in case of pressure burst,
- the safe distance for the personnel in case of decomposition.

<sup>5</sup> NFPA 400, 2019 Edition

- **Distance between storage tanks:** if no local regulation regarding distance between two hydrogen peroxide storage tanks we recommend to follow NFPA 30A (minimum distance = 1 meter between each tank)
- **Emissions / dispersion in case of decomposition:** as mentioned in chapter 2, calculations of droplet behaviour suggest, that majority of the air-borne liquid would fall within a 20 – 30 meters radius from the vessel. In addition, the dispersion behaviour of the

hydrogen peroxide cloud emitted through the safety vent also shows, that a toxic concentration is never reached at the ground level even though the cloud may drift in several kilometres from the source of release. If the decomposition occurs on the ground rather than in a vessel, then vapour dispersion distances could be extended further.

Gas and liquid phase explosion risk are not considered for the evaluation of the safety distance for the reasons mentioned in the [chapter 2](#).

## 6. Auxiliary equipment

General guidelines to be observed in the design of auxiliary equipment:

- Always contact the hydrogen peroxide producers in case of doubt about equipment described in this chapter.
- Use only approved **materials of construction** and suitable welding process as already specified in [chapter 4](#). Consult the list of accepted materials in [appendix 5](#): the compatibility of any material not listed shall be tested before use. Typical unacceptable materials are: graphite, brass, copper, nickel, bronze, chromium, iron and mild steel, synthetic rubbers.
- Take care that most **fluids (lubricants, hydraulic fluids, ...)** are incompatible with hydrogen peroxide. Selected silicone or fluorocarbon-based fluids are accepted (consult a hydrogen peroxide supplier).
- All materials after manufacture or repair require **cleaning** and metals also require **pickling and passivation** by suitable formulation. See [appendix 6](#).
- Avoid direct contact of **dissimilar metals** (especially aluminium and stainless steel), or install electrical insulated material or sacrificial spool
- All pipework's, pumps and equipment in which hydrogen peroxide could be trapped must be always protected to **prevent overpressure** caused by hydrogen peroxide decomposition.
- Avoid any accumulation of impurities (e.g. in dead ends or filters). The installation of filters should therefore be avoided. If a filter is required, consult a hydrogen peroxide producer for the design and installation of the filter.
- Label clearly all lines and equipment and **dedicate** them exclusively to hydrogen peroxide use.
- Ensure a **high standard of isolation** from other fluids (e.g. block and bleed connections).

### 6.1 Piping

All piping should be easily drainable; stagnant lines and dead ends should be avoided (against accumulation of impurities).

Pipework does not generally require insulation against freezing for the common commercial concentration (see physical properties of the hydrogen peroxide solutions in [chapter 1](#)).

The design of the installation should limit the possibility of trapping any section containing hydrogen peroxide. For this reason, the number of valves and fittings should be kept at a minimum. A **safety relief valve must be installed** wherever liquid trapping is possible.

Piping must be designed to prevent flow back by siphoning or any other means. A siphon breaker must be fitted if such an event is possible.

All open pipe connections must be protected from external contaminants by closing them when out of service.

### PIPE CONNECTIONS:

Connections in piping systems should be butt-welded or flanged. Socket welded or screwed connections should be used only in special situations (i.e. instruments). The use of welded neck flanges is preferred. The flanges can be of raised faces or tongue and groove type. The connections must be free of oil and grease.

Lines under pressure should be equipped with flange protection guards when using raised face flanges in the case of a risk of projection.

### GASKET:

a list of accepted material for the gasket is given in [appendix 5](#).

### SAFETY RELIEF VALVES:

The safety valve must allow the release of any gas generated as a result of the normal decomposition of non-contaminated hydrogen peroxide (standard commercial solutions). The generated flow of gas is low; for this reason, the minimum commercial size of safety valve is sufficient. The case of the large diameter and/or long pipes must be studied individually. Pay attention to the compatibility of all the materials of construction of the safety valve (especially the multiple internal elements).

It is useful to standardise set pressures and dimensions for each installation.

The discharge of the safety valve should be directed into a safe location. Discharge back into the storage tank is prohibited (contamination risk).

## 6.2 Pumps

Centrifugal pumps are usually used for hydrogen peroxide. Volumetric pumps are also acceptable. The use of other types of pumps should be discussed with an hydrogen peroxide producer.

**General recommendation:** an emergency stop should be possible from a safe location (control room or local). Materials of construction should be selected according to the table in [appendix 5](#).

### VALVES:

The criteria for the choice of the valves (including check valves) are:

- no possibility of trapping hydrogen peroxide in any position of the valve,
- compatible materials: this recommendation can be particularly difficult to observe because of the multiple elements in the valves: casing, shaft, gaskets, rings. Check all the elements of the valve in contact with the fluid.
- no need for lubricant.

Ball valves: a degassing hole must be drilled in the ball so that, while in the off position, the channel through the ball can be connected with the upstream liquid side. Those valves are commonly used for diameters below DN150. The hole diameter should be 3 mm minimum.

**Globe valves:** commonly used for all diameters.

**Butterfly valves:** used for diameters over DN150.

Diaphragm, plug and gate valves are **not** recommended.

### HOSES:

Hoses should be minimised in number and length, dedicated and properly connected. It is preferred to reserve hoses for use only on a temporary basis (install fixed pipes whenever possible).

Choose carefully the type of hoses and their materials. In case of doubt, ask a hydrogen peroxide producer (see material list in [appendix 5](#)).

### CENTRIFUGAL PUMPS:

#### Shaft seal:

- single mechanical seal
  - recommended material: SiC/SiC.
  - alternatives: glass filled PTFE, alumina ceramic
- O-ring: PTFE or perfluoroelastomers.

Avoid double mechanical seals (risk of hydrogen peroxide trapping) and packed glands (risk of hydrogen peroxide decomposition, incompatibility with lubricants).

Precautions should be taken to avoid pump operation against a dead end that may cause rapid temperature rise.

### VOLUMETRIC PUMPS:

Diaphragm, piston and gear pumps can be used. It is important to make a careful choice of materials of construction and intermediate fluid. The pump manufacturer should be informed about the risk associated with hydrogen peroxide.

Membranes should be in PTFE, stainless steel or zirconium. Only compatible materials of construction,

even on the non-peroxide side, should be allowed in case of membrane rupture.

The piston should be a PTFE gland packing- plunger.

Protect volumetric pumps against overpressure generated by a closed discharge line. In case of installation of a safety valve, the discharge should preferably be connected to the suction side of the pump.

## 6.3 Transfer to process

To prevent any back-flow, **a mechanical break upstream of the contact with any other product must be installed** (minimum requirement).

The recommended design is a double block and bleed system initiated by a low flowrate detection. Never rely only on check valves or a single isolation valve.

Another option is to install an intermediate tank between the storage tank and the injection in the process to realise this break.

This intermediate tank should have:

- a limited size
- an overflow, to prevent any back-flow in the hydrogen peroxide tank
- adequate venting, preferably as big as technically possible
- a temperature measurement (optional)
- a block and bleed system on the discharge line to the process

The intermediate tank can also be used as a dosing tank for the hydrogen peroxide.

## 6.4 Instrumentation

Users should seek advice from hydrogen peroxide producers for the determination of the most appropriate type of instrument.

Take care that instruments do not involve trapping risks and that materials of construction are approved.

If conveying fluids are used in the measuring sensors, the fluid must be compatible to allow possible equipment failures.

Instrument air must be oil free and dry.

## 6.5 Safety facilities

**Safety shower** and **eyebath** **must** be installed in the vicinity. They must be tested periodically.

**A water source must** be available for a dilution of spills and leaks. All water supplies should be easily accessible, clearly labelled and available at all times with protection against freezing.

## 6.6 Unloading section (for users):

Hydrogen peroxide must be preferably unloaded using a self-priming centrifugal pump; this pump must be dedicated to the use of hydrogen peroxide. The unloading by dry air (oil free) or nitrogen is nevertheless acceptable; in this case, the gas system should be equipped with a proper filter, pressure reducing valve, safety valve and pressure gauge (do not use engine discharge).

In order to prevent contamination (unloading of another product), **a physical barrier must be established (minimum requirement)**, for instance by a cap or a valve closed with a key, under the responsibility of a responsible member of the personal of the plant.

Coupling: a dedicated coupling is recommended.

Pipes must be **dedicated** to hydrogen peroxide: no cross connection, no common header.

**Label** clearly the unloading zone and pipes (particularly the connection point for unloading).

Any spillage resulting from a disconnection of the hoses must not represent any danger: it can be recovered in the bund of the storage or be evacuated after dilution with a large quantity of water.

## 6.7 Dilution installation

Dilution of the product, before, after or even during storage, is often practised because of the low concentration used in many applications, in order to reduce the transportation cost and/or the size of the storage tanks.

In case of a dilution before or during storage, use only demineralised or deionised water (typically, the requirement on the conductivity is lower than 1 µS/cm). It is not allowed to use steam condensate or boiler feed water. In case of a dilution after storage (or for direct use, without storage), the requirements on the quality of the water are not so high (respect the requirements of the process). It is recommended to perform stability

tests to validate the quality of the water (those tests can be done by the supplier/producer).

The transfer line for demineralised water should be constructed with materials compatible with hydrogen peroxide (this recommendation is mandatory for all sections of the line from where hydrogen peroxide back flow cannot be excluded). The design should ensure the impossibility to return hydrogen peroxide into the water distribution network (do not rely on a check valve or on a simple isolation valve). The configuration of the pipe connections between hydrogen peroxide and demineralised water lines should include an intermediate draining valve (block and bleed system).

# 7. Operations

## 1. Supply

The unloading of bulk hydrogen peroxide must be organised so that the following hazards are specifically avoided:

- Delivery of hydrogen peroxide to any destination other than its intended dedicated tank or via any route other than its dedicated pipework and associated equipment.
  - Delivery of any other substance to the hydrogen peroxide tank or via the hydrogen peroxide pipework and associated equipment.
  - Contamination of the hydrogen peroxide during the unloading procedure.
  - Overfilling of the hydrogen peroxide storage tank.
  - Leakage or spillage of the hydrogen peroxide, and resulting contact with people or environment.
  - Overpressure and/or underpressure beyond the limits of equipment.

In order to achieve these objectives, the following features will normally be required:

- Display of the orange regulatory transport label on the tank (hazard identification number and UN number)
- Validation of the product before unloading (check that it is indeed hydrogen peroxide).
- Unloading will preferably be by means of a suitable dedicated pump (either on the vehicle or the recipients installation). Alternatively, air or nitrogen can be used provided that they are clean, dry, filtered, oil free, equipped with adequate overpressure protection and that lines are blown out prior to unloading.
- The unloading procedure includes provision for confirmed identification of unloading point, prestart-up check for correct valve alignment and absence of defects, dedicated capped hoses, full personal protective equipment(except breathing apparatus) for people involved, check of adequate ullage in receiving tank, and continued supervision during unloading.
- The responsibility for the unloading operation must rest with the installation management throughout. Unloading operations must be performed by trained personnel.

## 7.2 Dilution

Dilution of hydrogen peroxide potentially has several adverse effects on its stability. In particular, the very act of dilution will reduce the concentration of stabilisers in the hydrogen peroxide and so their effectiveness. In addition, even low levels of contaminants which are inevitably present in water can have the ability to cause serious destabilisation. Dilution will also cause the pH to increase.

The effects of any dilution operation on stability must be assessed in advance. Hydrogen peroxide suppliers will normally offer advice or assistance if requested.

## 7.3 Handling

Handling operations should preferably be carried out in a dedicated, ventilated and clean area, free of combustible materials and heat sources. In accordance with normal industrial hygiene, activities such as smoking, eating and drinking should be prohibited.

Handling operations should be allied to approved methods and procedures, improvisation being forbidden. The following key principles should be embodied in operations:

- The need for care, especially in prevention of spills and contamination of the hydrogen peroxide.
- Scrupulous cleanliness.
- Good housekeeping.
- Avoidance of all contact with incompatible materials.
- Equipment being kept closed to keep out contamination, while still permitting decomposition gases to escape.
- Equipment being restricted to what is specifically suitable, clean, passivated (where appropriate), and labelled as for hydrogen peroxide only.
- Avoidance of any trapping of hydrogen peroxide during a long period, even if the section in question is equipped with an overpressure protection.
- Avoidance of use of inappropriate equipment by imposition of a rule to the effect that, whatever is not specifically approved, is forbidden.
- After use, portable equipment to be rinsed thoroughly with good quality water and drained.
- Decontamination by immediate drenching of anything which is contacted by hydrogen peroxide.
- For personal protective equipment refer to the manufacturers Safety Data Sheet.
- Proximity of and awareness of safety showers/adequate water supplies/eyewash bottle.
- Once removed, hydrogen peroxide must not be returned to the tank.

## 7.4 Maintenance

All maintenance work on a hydrogen peroxide installation should be controlled by a formal permit procedure which assesses the tasks to be undertaken, the current working conditions, and specifies appropriate safety precautions.

Because of the special engineering features required for materials of construction and fabrication techniques necessary for hydrogen peroxide systems, great care has to be exercised in repair, modification, cleaning or other maintenance operation. In particular the person(s) undertaking the work must have the necessary competences to ensure that only suitable materials, correctly pre-treated and fitted, are used.

For the replacement of fittings gaskets or other accessories, it must be ensured that only like for like replacement occurs. Experience shows that even minor apparently inconsequential differences can result in serious safety problems e.g. minor grade changes in gasket materials, or subcomponent change in a measurement probe.

Storage installations should be routinely inspected for signs of leakage, damage, disrepair and proper functioning of components. In addition, safety equipment must be regularly proof tested.

Before any maintenance or repair operation the installation parts involved have to be rinsed thoroughly with de-ionized water.

## 7.5 Disposal

All disposal operations must be carried out in compliance with all applicable regulations, in such a way that the safety of people and environment is protected. The main options are as follows:

- Hydrogen peroxide can be flushed to a sewer as long as it is diluted sufficiently, to not present a hazard in the drains. It is recommended to keep the concentration of the diluted product below 5% for safety purposes (local regulations might have lower limits). In addition, hydrogen peroxide can be destroyed at a waste

water treatment plant (limits to be consulted with local waste water treatment plant)<sup>6</sup>.

- Hydrogen peroxide can be prevented from entering the environment, and disposed of as a dangerous waste. This may be done by absorption on a non-combustible material, e.g. sand, vermiculite, or by decomposition. In these cases, particular care has to be taken with respect to the safety aspects.

# 8. Emergency response

## 1. Emergency planning

In sites where there are hydrogen peroxide tanks, it is imperative that an emergency response plan is available.

The emergency response plan, at least, shall provide directions for:

- actuation of an alarm signal,
- actions to be taken in case of dangerous situations with respect to hydrogen peroxide, such as decomposition, fire, spillage.
- allocation of responsibilities,
- procedures for notification of responsible management and authorities,
- evacuation procedures (e.g. warning system, evacuation routes, registration and care of evacuees)

All personnel directly or indirectly involved in the storage and use of hydrogen peroxide shall be familiar with the emergency response plan. The emergency response plan, where appropriate, shall also be discussed with and made available to the local authorities. This is especially important for the parts concerning off site help (e.g. fire brigade, hospital).

The emergency response plan shall be checked and updated in regular intervals. The effectiveness of the emergency procedures shall regularly be tested, ensuring that the people involved experience such an event once a year.

## 8.2 Runaway decomposition

There are two aspects of runaway decomposition, which must be taken into account. These are, the dynamics of its auto accelerating nature and the variety of its potential consequences.

Firstly, its auto accelerating nature is such that in its early stages, it can occur very slowly, even imperceptibly. However, as the decomposition progresses, it will

go faster and faster, becoming hotter and hotter and eventually generating large volumes of gas and vapour in a very short period.

Secondly, the rate of acceleration of a particular runaway decomposition event can be extremely variable, depending primarily on the nature of the causal contamination.

<sup>6</sup> Reach dossier

A particular decomposition emergency can develop over a period of e.g. few minutes or e.g. hours or even longer. At the point of discovery of a runaway decomposition, it is not at all obvious how much time may be available before the attainment of maximum rate of decomposition.

### GENERAL GROUND RULES:

The main principle to be applied is to ensure the safety of all personnel within range as the top priority. Actions to protect the environment or save product and/or equipment must be a secondary objective. Upon detection of a decomposition, the emergency procedure must adopt the following principle lines of action:

- **Removal of unnecessary/untrained personnel** from the zone of potential danger (criteria to be defined by discussion),
- **Communication** of state of emergency to other personnel and authorities as appropriate,
- If safe to do so, **intervention by trained and protected** personnel.

The intervention guidance is summarised below in the form of some important [general ground rules](#) followed by the available tactical choices:

1. It is essential to have a pre-planned emergency procedure.
2. All intervention actions must be with full protective clothing and by trained personnel.
3. In case of doubt or the unexpected, everybody should go to a safe location.
4. All hydrogen peroxide out of containment (overflow, emission, dumped) should be diluted as much as possible in accordance with chapter 7.5.
5. Authorities must be notified in the event of environmental exposure.
6. Medical contact with specific hydrogen peroxide treatment knowledge.

### RESPONSE OPTIONS:

In the event of a decomposition emergency the choice of response usually depends on two main factors:

- Knowledge of the actual rate of decomposition,
- The size of the installation.

Knowledge of the [decomposition rate](#) may be conveniently classified as follows:

- A. Visible emission from vent or audible gas escape from vent or temperature increase to safety alarm threshold. These are all signs of a decomposition, which may well be imminent and in all probability cannot be stopped (in case of conflicting evidence, audible and visual indicators should take precedence). The safe choices are evacuation and eventually remotely actuated emptying/dousing.
- B. Temperature increases to monitoring alarm threshold. Subject to the reliability of temperature indication, this is an incipient decomposition for which intervention time may well be available (until type A indications develop). In this case, investigation, local dousing/emptying or spray cooling may be considered.

### COMMENTS:

Concerning tank size, in general, to increase the size of the tank will inhibit the effectiveness of the addition of stabilisers or any external cooling of the tank. However, there is no uniquely defined relationship or correlation. Stabiliser addition is unlikely to be effective unless an engineered means of mixing is incorporated. Spray cooling is unlikely to be effective except in the early stages of decomposition and then not for large tanks.

In the event of a large vapour emission, the emergency plan must address the safety of the people in a downwind location. They should either escape in a direction perpendicular to the wind direction, or be indoors with windows and doors closed and preferably upstairs at the downwind side of the building. Water curtains may be deployed by the fire brigade in case of decomposition at the ground level (e.g. decomposition in the bund after dumping of the product) in order to limit the dispersion of the hydrogen peroxide vapours; the risk of overpressure of the tank should be considered for the position of the fire brigade (in relation with the safety distances).

## 8.3 Loss of containment

In case of a loss of containment, the emergency response must consider the risks against the person and the environment, as well as the specific risk of fire, or even explosion in the event of contact with flammable materials if confined e.g. in drains, pits or closed collection tanks.

### 8.3.1 FIRE FIGHTING

Hydrogen peroxide will not burn, although it can initiate combustion of combustible materials and contribute to an increased ferocity of burning. The application of water is recommended for all fires involving hydrogen peroxide. In the event of hydrogen peroxide being exposed to an adjacent fire, water spray cooling of the hydrogen peroxide equipment may be applied to prevent accelerated decomposition, but only if this can be achieved from a safe location. This recommendation applies mainly to small tanks; for larger tanks, experience shows that it is unlikely that a surrounding fire would cause a hazardous increase of the temperature of the hydrogen peroxide.

In all cases personnel protective equipment is required. If there is a risk of explosion, water application must be from behind protection.

### 8.3.2 ENVIRONMENT

Hydrogen peroxide should not be discharged to water courses or soil. If necessary, spillages should be contained, by use of an inorganic absorbent such as sand or vermiculite, to prevent entry to the environment.

In case of discharge to the environment, the appropriate authorities should be notified without delay. Refer to [chapter 7.5](#) for details.

Under no circumstances should hydrogen peroxide be disposed of by transfer to any vessel. Especially not use any general purpose waste tankers or vacuum trucks.

### 8.3.3 FIRST AID

Hydrogen peroxide is corrosive to the skin and mucous membranes and can cause severe damage to the eyes while direct contact. At any place where hydrogen peroxide is stored or handled, appliances must be available for extensively washing skin and eyes.

Refer to the safety data sheet (SDS) for first aid measures.

## 9. Management

The management shall appoint a sufficient number of well instructed personnel to manage, to supervise and to handle the hydrogen peroxide.

The management shall:

- provide the technical means and facilities to store the hydrogen peroxide in a correct and safe manner,
- provide accurate and unambiguous instructions for proper handling of hydrogen peroxide,
- ensure adequate and sufficient maintenance, inspections and operating procedures,
- ensure emergency and fire fighting plans.

The management shall audit the above-mentioned elements regularly. Accidents or incidents shall be effectively investigated. Corrective actions must be implemented, their efficiency must be checked afterwards.

The management shall ensure that no modification of the installation and operating practises can be carried out without authorisation from competent responsible persons.

The management shall take care that the personnel involved in storage and handling shall be given adequate instruction and training, both in safe and proper handling of hydrogen peroxide, and in emergency procedures to deal with spillage, contamination, decomposition, fires, ingestion, inhalation, skin and eye contact. Refreshment courses should be given at least once a year.



# Appendix 1

## Decomposition kinetics of Hydrogen Peroxide

Experimental results for information only (dependent on stabilisation formulation)

Reaction Kinetics



$$d[\text{H}_2\text{O}_2]/dt = -k [\text{H}_2\text{O}_2]$$

$$\text{with: } k = 0.81 \times 10^7 \times K_f \times e^{(-10357/T)} \text{ min}^{-1}$$

for uncontaminated product  $K_f = 1$

Decomposition kinetics are accelerated by :

- Contaminants (Fe, NaOH, ...): increase of  $K_f$
- Increase of temperature
- Increase of Pressure (limitation of water vaporisation thus increase of temperature)

For contaminated product, see example of  $K_f$  values in the following tables (k values at 25°C).

| Iron content<br>(mg/kg) | $k \times 10^8$<br>min <sup>-1</sup> | $K_f$ | Comments                                             |
|-------------------------|--------------------------------------|-------|------------------------------------------------------|
| 0.12                    | 0.95                                 | 1.46  | Standard technical<br>grade 70% hydrogen<br>peroxide |
| 0.37                    | 3                                    | 4.6   |                                                      |
| 7.76                    | 7.56                                 | 11.6  |                                                      |
| 15.52                   | 9.42                                 | 14.4  |                                                      |
| 31.04                   | 64.55                                | 98.9  |                                                      |
| 38.81                   | 912.5                                | 1398  |                                                      |
| 46.6                    | 6763                                 | 10366 |                                                      |
| 10                      | 4476                                 | 6861  | Unstabilized 70%<br>hydrogen peroxide                |
| 20                      | 21760                                | 33360 |                                                      |

### EXPERIMENTAL RESULTS WITH ADDITION OF CAUSTIC SODA IN STABILISED 70% HYDROGEN PEROXIDE

| NaOH 100%<br>(kg/m <sup>3</sup> ) | pH       | k x 10 <sup>8</sup><br>min <sup>-1</sup> | K <sub>f</sub> |
|-----------------------------------|----------|------------------------------------------|----------------|
| 0                                 | 0.55     | 3                                        | 4.6            |
| 2                                 | 4.85     | 105                                      | 160            |
| 5.8                               | 5        | 295                                      | 452            |
| 7                                 | 5.45     | 863                                      | 1322           |
| 12                                | 5.8      | 2283                                     | 3499           |
| 17                                | 6        | 35200                                    | 53950          |
| 26.4                              | 6.2/6.45 | 70083                                    | 107415         |

#### CASE STUDY:

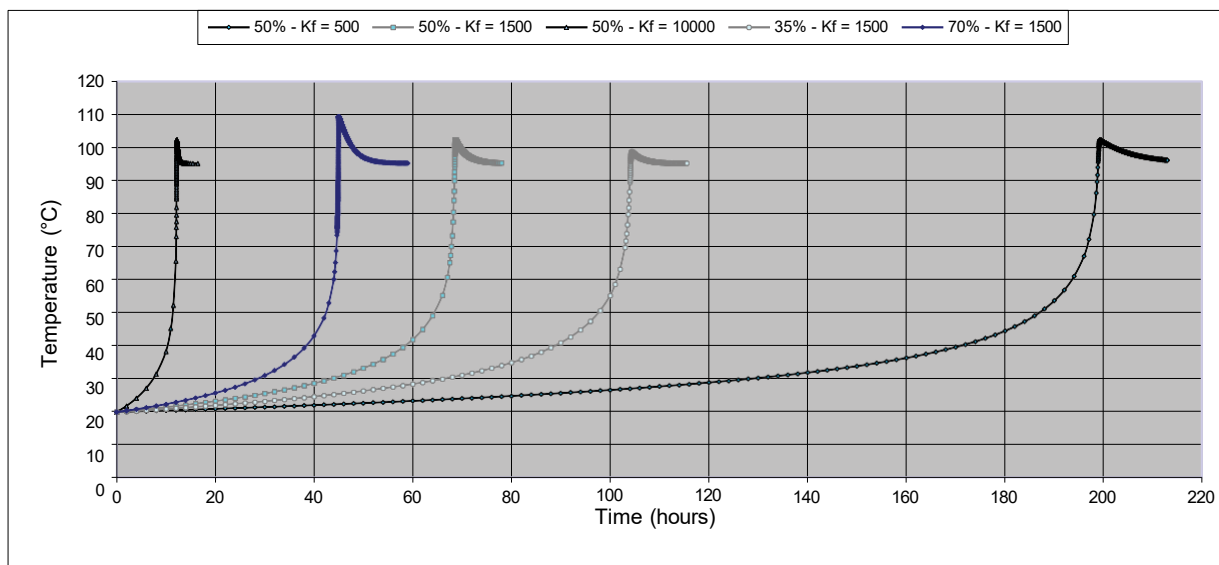
The following table and graph give, using a simplified thermodynamic model, an orientation concerning the variation of the temperature in the case of decomposition. The calculations are made under adiabatic conditions (which is conservative). The influence of the concentration and decomposition factor K<sub>f</sub> on the decomposition kinetics can be seen through the 5 chosen examples:

- concentration 50%, K<sub>f</sub> = 500
- concentration 50%, K<sub>f</sub> = 1500
- concentration 50%, K<sub>f</sub> = 10000
- concentration 35%, K<sub>f</sub> = 1500
- concentration 70%, K<sub>f</sub> = 1500

The following table indicates the temperature variation (in °C/h) at different temperatures, for the 5 above mentioned cases:

|      | 50% - K <sub>f</sub> 500 | 50% - K <sub>f</sub> 1500 | 50% - K <sub>f</sub> 10000 | 35% - K <sub>f</sub> 1500 | 70% - K <sub>f</sub> 1500 |
|------|--------------------------|---------------------------|----------------------------|---------------------------|---------------------------|
| 35°C | 0.3                      | 0.7                       | 3.5                        | 0.5                       | 1                         |
| 45°C | 0.8                      | 1.8                       | 10                         | 1.2                       | 2.5                       |
| 50°C | 1                        | 2.6                       | 15                         | 2                         | 5                         |
| 60°C | 2.5                      | 8                         | 25                         | 4                         | 10                        |
| 70°C | 5                        | 35                        | 90                         | 10                        | 23                        |

The variation of temperature as a function of the time is represented on the following diagram. It shows that temperature alone is not sufficient to predict a runaway reaction of hydrogen peroxide. The rate of temperature increase must also be taken into account.



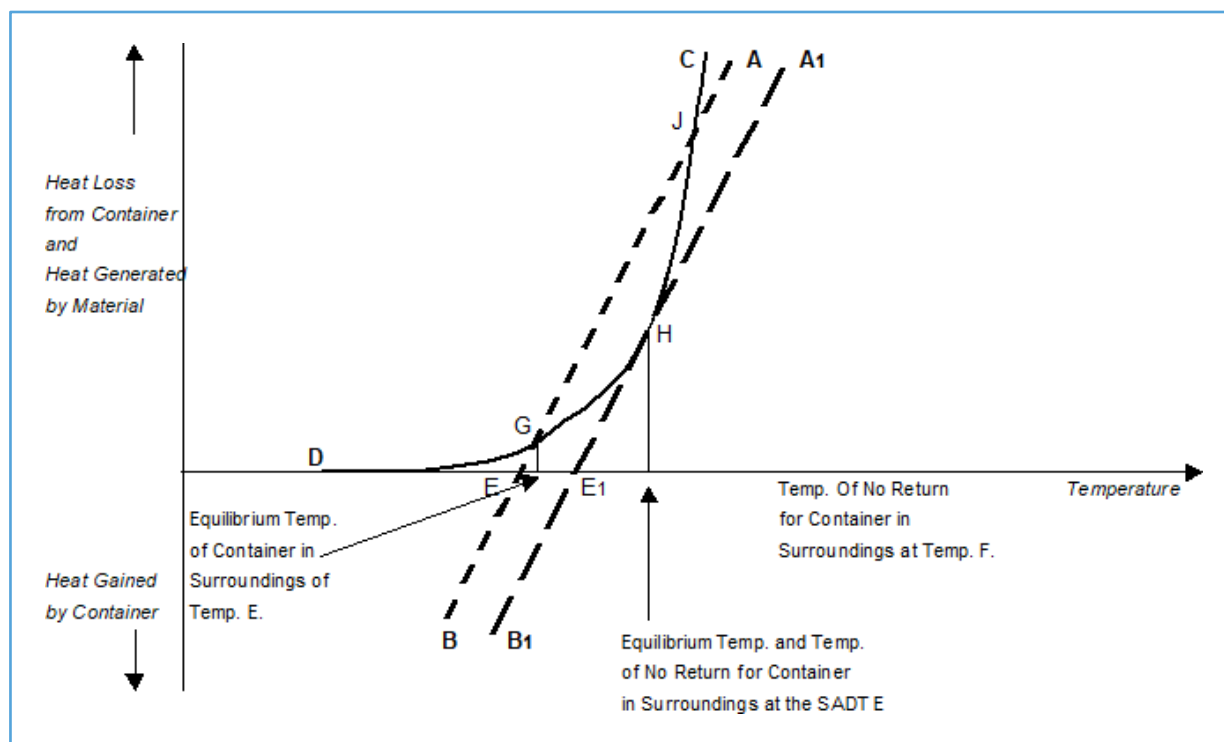
## Appendix 2

### Self-Accelerating decomposition temperature

The Self Accelerating Decomposition Temperature (S.A.D.T.) is a very important parameter which is continually used in peroxygen technology. It is also often not fully understood.

Hydrogen peroxide and most peroxygen compounds are basically unstable, continuously decomposing with the evolution of heat. Material in a container will therefore progressively self-heat if the rate of heat loss to the surroundings is less than the rate of heat generation. As the temperature of the material increases, the decomposition rate and the rate of heat evolution increases. An accelerating reaction results. The S.A.D.T. of a system is the temperature of the surroundings above which a given quantity of material in a container of a given size and shape will generate an accelerating reaction. It is specific to that particular container and to that particular weight of the material. S.A.D.T.'s are, however, specified for many unstable substances in product descriptions and in storage and transport regulations without any description of the container's size and shape, or of amount of its contents. These S.A.D.T.'s are derived from the standard maximum sized package and quantity of material which are used for products of that particular class. These conditions must be known before these standard S.A.D.T.'s can be used as anything more than a general guide to systems which involve different amounts of materials in containers of different size and shape.

**FIGURE 1 - TYPICAL S.A.D.T. DIAGRAM**



In **FIGURE 1** the straight line AB shows the rate of heat loss from a container and its contents to the surroundings, as a function of temperature. The curved line CD shows the relationship between the material's temperature and its rate of heat evolution.

Points E and EI are temperatures of the surroundings, and if the container and its contents are at these temperatures they will obviously lose no heat.

Point G is the point at which temperature of the container and its contents are in equilibrium with surroundings at temperature E.

If the temperature of the surroundings increases to EI there is a new temperature loss line AIBI, which is tangential at point H to the heat evolution line CD. Container and contents will just remain in equilibrium with the surroundings when the temperature of the surroundings reach a temperature of EI. Any further increase in temperature of the surroundings and contents and container will progressively self-heat in an accelerating mode, irrespective of their initial temperature.

The surroundings temperature EI, is the S.A.D.T. of the system.

Point J is the Point of No Return. The temperature at point J is the Temperature of No Return (T.N.R.). Material above this temperature, put into a container in surroundings of temperature E, will self-heat in an accelerating mode.

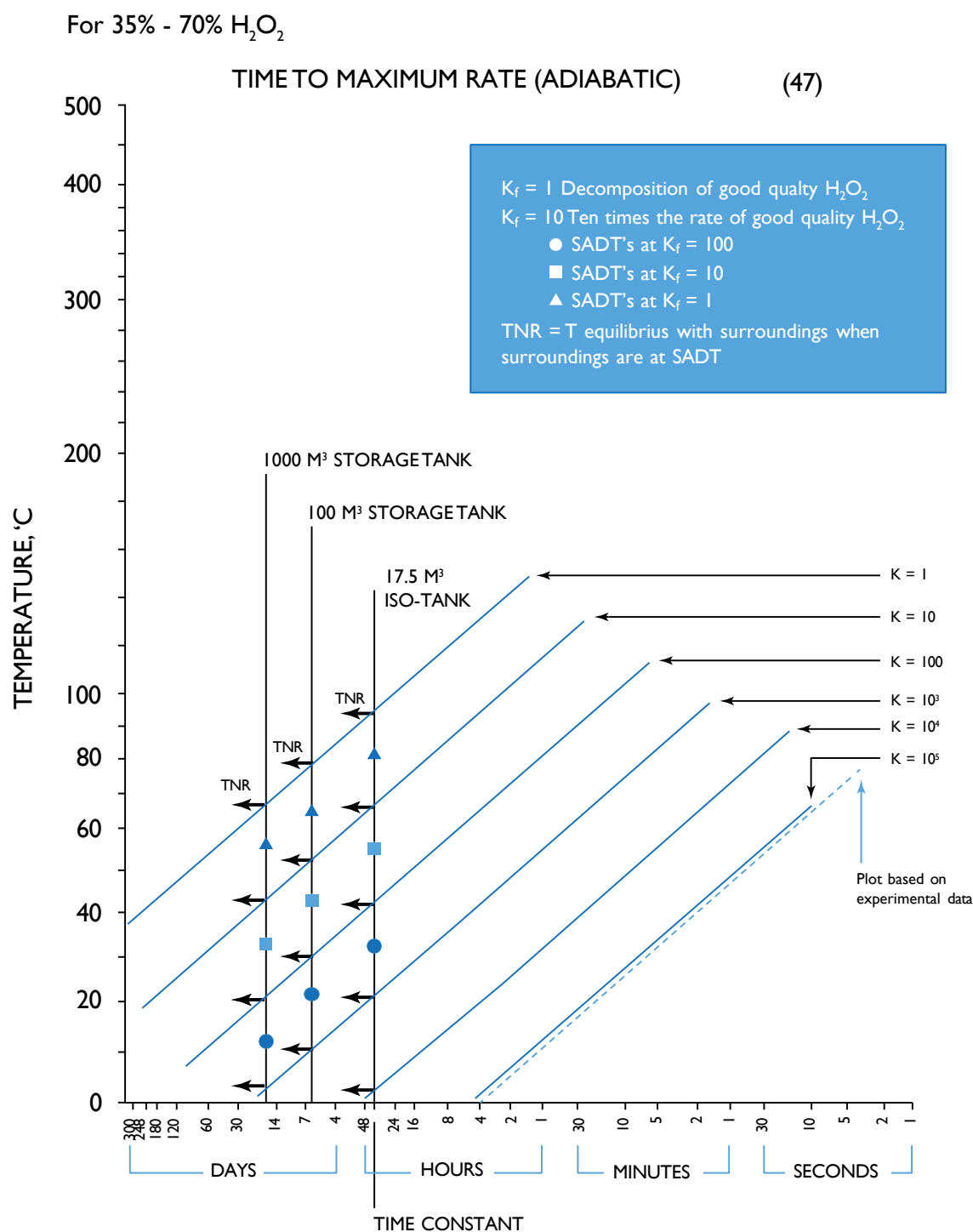
At the S.A.D.T. the temperature of the Point of No Return coincides with the temperature at which the material and container are in equilibrium with its surroundings.

Deterioration of stability will move curve CD to the left, lowering the S.A.D.T. and vice versa. Increases of size and proportionally, contents in a series of containers of given geometry will reduce the slope of the straight line AB, giving progressively lower S.A.D.T.'s. Changes in geometry which decrease the surface/volume ratio will also reduce the slope of AB and the S.A.D.T.

As hydrogen peroxide is always decomposing and evolving heat, there will be a maximum size of storage tanks of a given geometry which can be filled with hydrogen peroxide of a particular stability. As tanks increase in size, the amount of contamination which can be tolerated before the S.A.D.T is reached gets smaller and smaller. There will also be a maximum temperature for the hydrogen peroxide which can be filled into a tank of given size and shape, in surroundings at a particular temperature.

In practical systems, considerations of S.A.D.T. do not have any great influence on the choice of storage tank sizes. Standard commercial grades of hydrogen peroxide can be stored in tanks of over 1000 tonnes capacity in the hottest climates.

**FIGURE 2 - T.N.R. 'S AND S.A.D.T. 'S FOR TYPICAL 100 m<sup>3</sup> AND 1000 m<sup>3</sup> TANKS AND 17.5 m<sup>3</sup> I.S.O. TRANSPORT TANK**



S.A.D.T.'s and equilibrium temperatures of tank contents with the surroundings at the S.A.D.T., have been calculated and plotted in **FIGURE 2**.

For strengths of hydrogen peroxide between 35% and 70%, the decomposition/heat rates change very little and a single rate equation can be used to give adequate accuracy.

Very high strength materials do require modified rate equations. The S.A.D.T. and T.N. R. for a 17.5 tons ISO tank full of 86% with  $K_f = 1$  are 68°C and 80°C, compared with 81°C and 94°C for 35% - 70% material.

## Appendix 3

### Example of calculation of the overpressure related to a burst of hydrogen peroxide tank using the TNT equivalence method

The following calculation method is only indicative. Other methods or criteria can be used to estimate the consequences of a tank burst.

We consider the following overpressure values as important for the determination of safety distances:

**140 mbar:** Lower limit for the major destruction of buildings. Considered also as a limit of lethality for people, not because of the effect of the overpressure on human beings, but because it corresponds to an empirical limit for the risk of projection of material.

**50 mbar:** Minor destruction of buildings (glass, light inner wall or weak structures). Limit for small injuries caused by glass breakage.

According to a chart, we can determine the “reduced distance”  $\lambda$  related to those both cases:

$$\lambda = R / \sqrt[3]{m}$$

R : distance to the centre of explosion

m : equivalent kg TNT

$$\lambda = 10 \text{ for } 140 \text{ mbar} \quad \rightarrow \quad \lambda = 25 \text{ for } 50 \text{ mbar}$$

For the calculation of **m**, we use the following calculation principle:

Energy released during the pressure burst (estimated by isoenthalpic expansion energy of the gaseous phase):

- $\Delta E = PV \times [1 - (P/P_a)^{(1-\gamma)/\gamma}] / (\gamma - 1)$  (in Joules)
- P: rupture pressure (Pa)
- P<sub>a</sub>: outside pressure (atmospheric –  $1.013 \times 10^5$  Pa)
- V: gas phase volume of the tank (m<sup>3</sup>)
- $\gamma = 1.4$  (ratio of specific heats)

50% of  $\Delta E$  is considered to be utilised for the blast.

1kg TNT = 3.72MJ.

Caution: in the above calculation, the rupture pressure should not be confused with the design pressure. Rupture pressure of low pressure tank can be much higher than the design pressure.

With this calculation we can consider different explosion cases, in relation with the volume and the rupture pressure of the tank. Only the gas volume is taken into consideration for the calculation; it is assumed that the tank is filled with 50% hydrogen peroxide.

|                                |      |       |      |       |
|--------------------------------|------|-------|------|-------|
| Total volume (m <sup>3</sup> ) | 500  | 100   | 20   | 5     |
| Volume V gas (m <sup>3</sup> ) | 250  | 50    | 10   | 3     |
| P rupture (bar g.)             | 0.2  | 1.0   | 1.0  | 1.0   |
| $\Delta E$ (MJ)                | 3.8  | 4.4   | 0.9  | 0.3   |
| m ~ TNT (kg)                   | 0.51 | 0.6   | 0.1  | 0.04  |
| R 140 mbar                     | 8 m  | 8.4 m | 5 m  | 3.4 m |
| R 50 mbar                      | 20 m | 21 m  | 12 m | 8.5 m |

This calculation should be performed in each individual case for the determination of the effect of a pressure burst of the tank (if considered to be possible). The distances resulting from the calculation should be considered in the safety management of the plant (protection of the personnel and equipment).

# Appendix 4

## Methodology for designing hydrogen peroxide storage vents

This calculation approach<sup>7</sup> can be used in the case of a foreseeable maximum contamination scenario. According to this approach, the required vent area can be obtained by the following relation:

$$A = f(c, p, K_f) \approx 0.35 (c / 100 - c) (K_f / \sqrt{p})$$

|      |                |                                                                          |                                                       |
|------|----------------|--------------------------------------------------------------------------|-------------------------------------------------------|
| with | A              | vent area                                                                | cm <sup>2</sup> /t H <sub>2</sub> O <sub>2</sub> 100% |
|      | c              | H <sub>2</sub> O <sub>2</sub> concentration                              | % weight                                              |
|      | p              | max. operating storage pressure                                          | mbar g                                                |
|      | K <sub>f</sub> | H <sub>2</sub> O <sub>2</sub> decomposition rate factor (see appendix 1) |                                                       |

c is known. p is the maximum allowed pressure; it shall be less than or equal to the design pressure. The difficulty is to estimate the decomposition rate factor K<sub>f</sub>.

This methodology takes into account:

- the storage volume and the hydrogen peroxide concentration
- the storage max. operating pressure
- the hydrogen peroxide quality
- the types and max. quantity of contaminants.

The last two parameters must be evaluated case by case and depend on:

- the connections with the storage
- the prevention equipment (dedicated coupling ...)
- the operators experience (producers/customers ...).

The methodology makes some assumptions:

- vapour phase release only
- K<sub>f</sub> = 50 – 1500 (although extrapolation is probably safe)
- fill level = 50 – 90%
- overpressure = 4 – 167 mbar

it is recommended the computed area is multiplied by an adequate over-design factor.

<sup>7</sup> Protection of hydrogen peroxide storage tank against overpressure – J.C. Adrian, H. Lagarrigue - 1993

**Calculation examples:**

$p = 50 \text{ mbar}$

$K_f = 1500$

|               |                                                               |
|---------------|---------------------------------------------------------------|
| - c = 35 wt % | A = 40 cm <sup>2</sup> /t H <sub>2</sub> O <sub>2</sub> 100%  |
| - c = 50 wt % | A = 74 cm <sup>2</sup> /t H <sub>2</sub> O <sub>2</sub> 100%  |
| - c = 70 wt % | A = 173 cm <sup>2</sup> /t H <sub>2</sub> O <sub>2</sub> 100% |

**Comparison with other calculation methods:**

The results obtained with this  $K_f$  value are coherent with other usually used values, e.g.:

200 cm<sup>2</sup>/t H<sub>2</sub>O<sub>2</sub> 100% (recommended for small storage tanks)

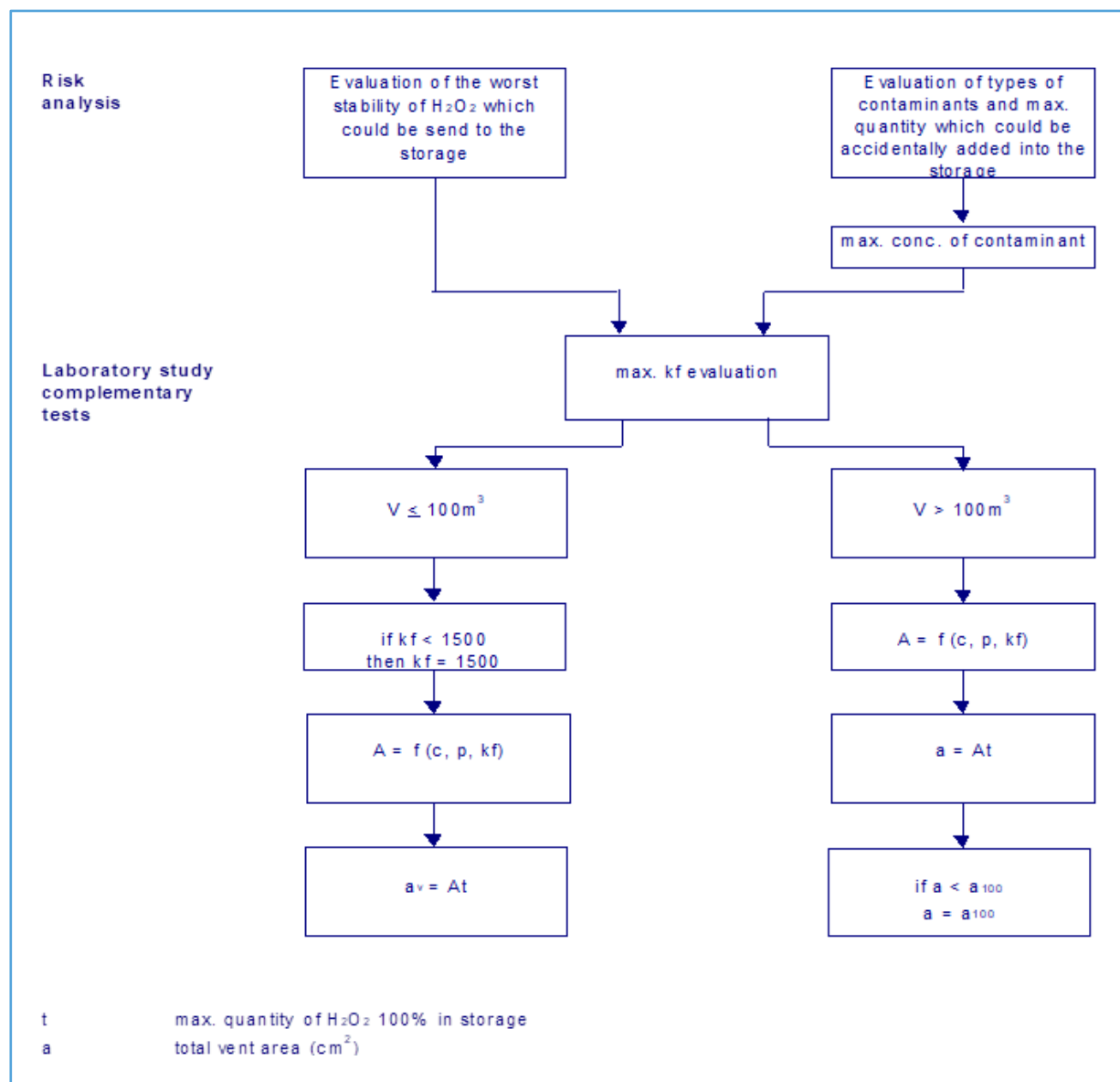
Factory Mutual method:  $d = a \times V^{0.493}$

with d: diameter of the vent (cm)

V: volume of the hydrogen peroxide stored (m<sup>3</sup>)

a: constant depending on the hydrogen peroxide concentration (see following table)

| hydrogen peroxide concentration | "a" values | Vent size cm <sup>2</sup> /t H <sub>2</sub> O <sub>2</sub> 100% |
|---------------------------------|------------|-----------------------------------------------------------------|
| 35                              | 4.77       | > 42                                                            |
| 50                              | 6.74       | > 56                                                            |
| 70                              | 15.8       | > 205                                                           |

**Proposed methodology:**

# Appendix 5

## List of recommended materials

| Part         | Material                          | Class | Hydrogen peroxide conc. | Comments                                                                                                                                                                                                                |
|--------------|-----------------------------------|-------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Storage tank | <u>Stainless steel:</u>           |       |                         |                                                                                                                                                                                                                         |
|              | 304L (1.4306)                     | 1     | Up to 70%               | Needs pickling and passivation.                                                                                                                                                                                         |
|              | 316L (1.4404 – 1.4435)            | 1     | Up to 70%               |                                                                                                                                                                                                                         |
|              | 316Ti (1.4571)                    | 1*    | Up to 70%               |                                                                                                                                                                                                                         |
|              | 316 (1.4401)                      | 2     | Up to 70%               |                                                                                                                                                                                                                         |
|              | <u>Aluminium alloys:</u>          |       |                         |                                                                                                                                                                                                                         |
|              | Al 99.5 (1060, 1050, 1080A)       | 1     | Up to 70%               | Needs passivation.                                                                                                                                                                                                      |
|              | Al 5254, Al 5652                  | 1     | Up to 70%               | Pitting can occur in the presence of chloride ions.                                                                                                                                                                     |
|              | Al-Mg3                            | 1*    | Up to 70%               |                                                                                                                                                                                                                         |
|              | <u>Plastics:</u>                  |       |                         |                                                                                                                                                                                                                         |
|              | HDPE                              | 1     | Up to 60%               | For small tanks (up to 50 m <sup>3</sup> ).<br>Susceptible to physical damage.                                                                                                                                          |
|              | XLPE                              | 1     | Up to 50% <sup>8</sup>  | Should not contain any pigments, mineral fillers or catalytic residues incompatible with hydrogen peroxide.<br><br>If exposed to sunlight, should contain suitable level of anti-oxidants and compatible UV stabilisers |
|              | Stainless steel with PVDF coating | 1     | Up to 70%               |                                                                                                                                                                                                                         |
|              | Stainless steel with PFA coating  | 1     | Up to 70%               |                                                                                                                                                                                                                         |

<sup>8</sup> Based upon current experience

| Part                                  | Material                            | Class | Hydrogen peroxide conc. | Comments                                                                                                                                  |
|---------------------------------------|-------------------------------------|-------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Piping<br>(pipe and fittings)         | <u>Stainless steel:</u>             |       |                         | Needs pickling and passivation                                                                                                            |
|                                       | 304L (1.4306)                       | 1     | Up to 70%               |                                                                                                                                           |
|                                       | 316L (1.4404 – 1.4435)              | 1     | Up to 70%               |                                                                                                                                           |
|                                       | 316Ti (1.4571)                      | 1*    | Up to 70%               |                                                                                                                                           |
|                                       | <u>Aluminium alloys:</u>            |       |                         |                                                                                                                                           |
|                                       | Al 99.5 (1060, 1050, 1080A)         | 1     | Up to 70%               | Needs passivation.                                                                                                                        |
|                                       | Al 5254, Al 5652                    | 1     | Up to 70%               | Pitting can occur in the presence of chloride ions.                                                                                       |
|                                       | <u>Plastics:</u>                    |       |                         |                                                                                                                                           |
|                                       | HDPE                                | 1     | Up to 60%               | Inherently brittle, requires protection from impact and care in installation.                                                             |
|                                       | PTFE or stainless steel lining PTFE | 1     | Up to 70%               |                                                                                                                                           |
|                                       | PVC                                 | 2     | Up to 50%               |                                                                                                                                           |
| Cast constructions<br>(pumps, valves) | <u>Stainless steel:</u>             |       |                         | Needs pickling and passivation.                                                                                                           |
|                                       | 304 (1.4301)                        | 2     | Up to 70%               |                                                                                                                                           |
|                                       | 316 (1.4401)                        | 1     | Up to 70%               |                                                                                                                                           |
|                                       | 316Ti (1.4571)                      | 2     | Up to 70%               |                                                                                                                                           |
|                                       | <u>Plastics:</u>                    |       |                         |                                                                                                                                           |
|                                       | PTFE                                | 1     | Up to 70%               | Inherently brittle, requires protection from impact and care in installation.                                                             |
|                                       | PVC                                 | 2     | Up to 50%               |                                                                                                                                           |
|                                       | HDPE                                | 2     | Up to 60%               |                                                                                                                                           |
|                                       | PVDF                                | 2     | Up to 70%               |                                                                                                                                           |
| Gasket                                | Pure massive PTFE                   | 1     | Up to 70%               | Pure massive PTFE is susceptible to creep; suitable for tongue and groove flanges. For raised faces, prefer the others qualities of PTFE. |
|                                       | Expanded PTFE                       | 1     | Up to 70%               |                                                                                                                                           |
|                                       | Glass loaded PTFE                   | 1     | Up to 70%               |                                                                                                                                           |
|                                       | Perfluoroelastomer                  | 1     | Up to 70%               |                                                                                                                                           |

| Part                | Material                                           | Class | Hydrogen peroxide conc. | Comments                                                                                                                         |
|---------------------|----------------------------------------------------|-------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------|
| Hoses               | <u>Stainless steel:</u>                            |       |                         |                                                                                                                                  |
|                     | 304L (1.4306)                                      | 1     | Up to 70%               | Needs pickling and passivation.                                                                                                  |
|                     | 316L (1.4404 – 1.4435)<br>(with outer SS braiding) | 1     | Up to 70%               | Excellent chemical resistance but prone to mechanical fatigue. Not recommended for big hoses (heavy and difficult to manipulate) |
|                     | <u>Plastics:</u>                                   |       |                         |                                                                                                                                  |
|                     | PE                                                 | 2     | Up to 70%               |                                                                                                                                  |
|                     | Reinforced PVC                                     | 2     | Up to 50%               |                                                                                                                                  |
|                     | PTFE convoluted with outer SS braiding             | 1     | Up to 70%               |                                                                                                                                  |
| External bolts      | Cadmium plated or stainless steel                  |       |                         | Prevent rusting                                                                                                                  |
| Pipe thread sealant | PTFE tape                                          |       |                         | Ordinary lubricants should never be used                                                                                         |
| Thermowell          | Stainless steel (316, 304)                         |       |                         | Fluid: selected silicone based or fluorocarbon based                                                                             |

### Classification:

1: Materials that are fully compatible with hydrogen peroxide and suitable for a long-term contact.

\* suitable for temperatures below 60°C (e.g. storage tank, pipes), accelerated corrosion at higher temperatures (e.g. vaporizer in aseptic packaging machines)

2: Materials that are satisfactory for repeated short term contact with hydrogen peroxide – performance dependent upon grade of material used.

3: The list is more a general overview and there is no claim to completeness. Depending on stabilizers, concentration and purity there can be big differences between specific hydrogen peroxide formulations and therefore the suitability of materials.

4: The material compatibility chart is based on past publications and aims at common bulk storage and handling of hydrogen peroxide. The suitability of any construction materials must always be carefully matched to the exact hydrogen peroxide product used (concentration, purity, stabilization), which can only be done by the respective manufacturer/supplier. It is not a list intended for any special equipment design (e.g. vaporizers, high temperature handling, etc.).

# Appendix 6

## Surface treatment of equipment in contact with Hydrogen Peroxide

The rules presented in this appendix shall be used for the treatment of all stainless steel or plastic equipment in contact with hydrogen peroxide (tank, pipes, valves, accessories). Any equivalent surface treatment procedures may be used. For aluminium or other construction materials, the following procedure don't apply; consult a hydrogen peroxide producer.

### I. Treatment of stainless steel

#### 1. SCOPE AND PURPOSE :

This procedure shall apply to the surface treatment stainless steel mentioned in [Appendix 5](#). Those steels cover themselves under the influence of atmospheric oxygen with an invisible passive layer that provides good corrosion resistance. Oxide films, hammer scales, annealing colours, and residues of weldslag – as produced in annealing, welding or fabrication – are not passive layers. These lower the chemical resistance of steel, just like embedded foreign matter, scratches or other mechanical damage and must therefore be removed. This has to be done using the following procedures. These procedures are very specialised and should be obtained from or validated by a hydrogen peroxide producer. They assume that welds have been ground and polished as appropriate and verified by radiography during construction.

#### 2. GENERAL:

The treatment procedure has to take place before the filling with hydrogen peroxide. It must be ensured that no contamination occurs after treatment.

The following products are forbidden:

- chlorinated and halogenated solvents
- halogen ions (except for the pickling process)
- sodium and potassium hydroxides

Safety precaution the applicable codes and standards must be observed. The treatment fluids must be disposed of correctly in respect of the environment.

The composition of the treatment solutions (pickling and passivation) will be established by the surface treatment company and/or with assistance of a hydrogen peroxide producer.

Water quality: water of drinking water quality with a maximum chloride content of 25 ppm is required for the preparation the solutions and for rinsing after pickling.

### 3. GLOBAL OPERATION PROCEDURE:

#### **Pre-treatment / Degreasing:**

A mechanical process can be necessary to remove annealing colours and hammer scales. Brushing has to be performed with austenitic wire brushes. A simple brushing can be sufficient wherever no greater demands on corrosion resistance are made, for instance, for outside walls of apparatus and piping unless they are exposed to an aggressive atmosphere. Layer of hammer scale, adherent residues of slag, and embedded foreign matter cannot be completely removed by brushing.

Degreasing: this treatment will be executed by spraying or by complete dipping. The fluid is a solvent based on phosphoric acid or a detergent.

#### **Pickling:**

The pickling process aims to remove by dissolution the surface layer of metal. The treatment process will be executed by spraying or by complete dipping, with pickling liquid or paste. Solutions with an iron content higher than 8 g/l shall not be used. The pickling temperature must not exceed 50°C; in general room temperature is sufficient. The maximum duration of the pickling process must be assessed in order to avoid a degradation of the metal surface.

#### **Flushing:**

It will be executed with demineralised water or drinking water if suitable at ambient temperature with hydro-pneumatic spray gun. The end of the flushing must be determined by the pH of the effluent being the same as the water source.

#### **Passivation:**

The passivation process aims to provide a protective oxide film on the metal surface. Passivation occurs naturally in contact with oxygen of air. For users installations, it is recommended to passivate using a nitric acid solution.

#### **Final flushing:**

Final flushing shall be carried out using demineralised water. The end of the flushing must be determined by the pH of the effluent being the same as the water source.

### 4. INSPECTION

Before filling the installation with high concentrated hydrogen peroxide, it should be inspected and accepted by a hydrogen peroxide producer. It is common to perform a test with diluted hydrogen peroxide in order to verify the condition of the tank before the first delivery.

## 2. Treatment of Plastics

Visually inspect the internal surfaces of vessels and remove any adhering material.

Sweep out any loose debris.

Wash with a hot water (50°C) dilute aqueous solution of detergent. It is recommended that a 1 – 5 % solution of a good quality dodecyl benzene sulfonate based detergent is used. This washing may be achieved via spaying, scrubbing or swabbing.

Following washing, the equipment should be emptied and thoroughly flushed with demineralised water.

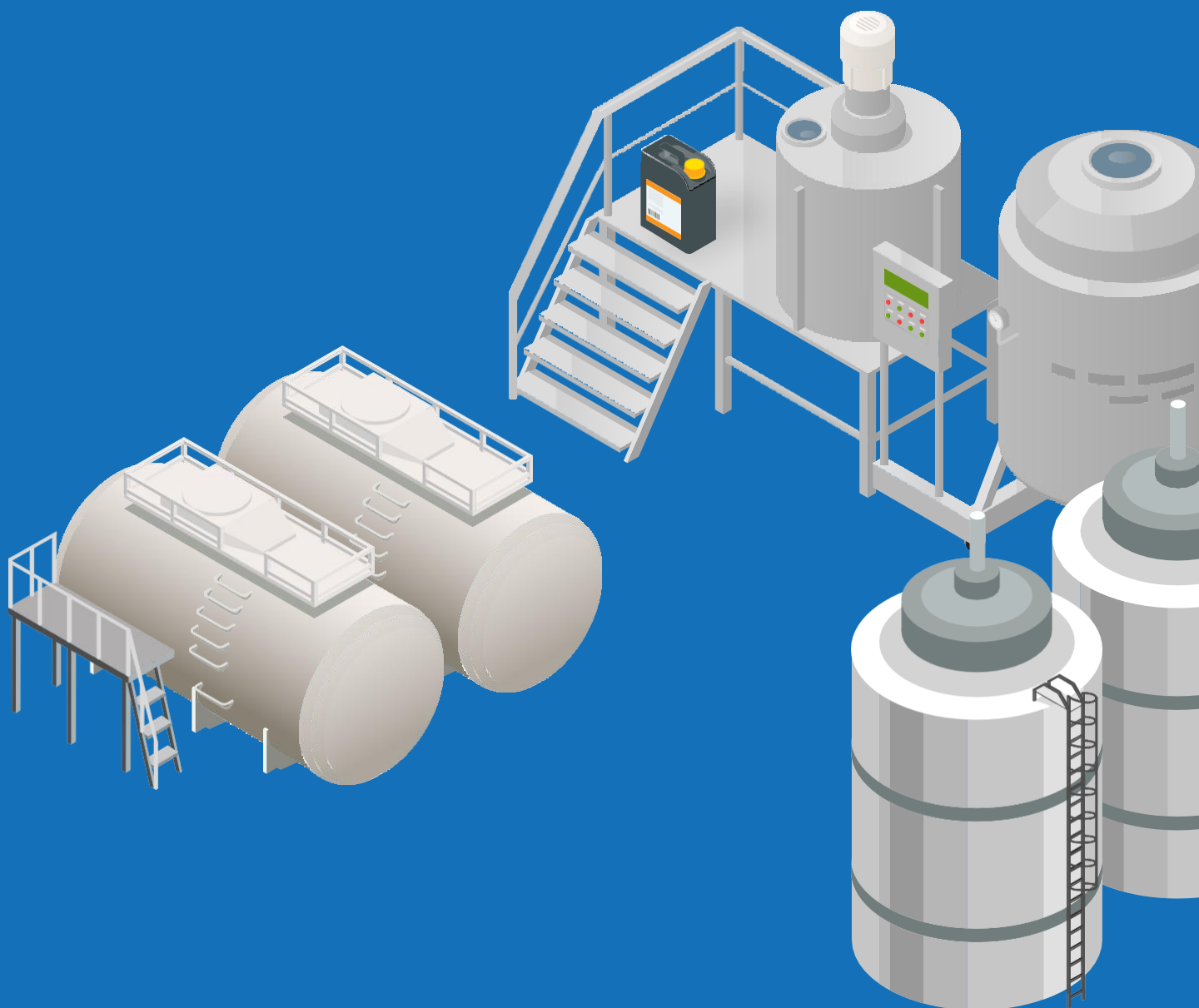
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