Guideline on the safety related requirements of the ChemCar-Competition
Rev. 9

ChemCar 2021
Introduction

This guideline lists question complexes, documentations and verifications that are required for the safety consideration of the submitted ChemCar Safety Concepts. Without these documents and verifications a qualified evaluation of the concepts is not possible and thus a security approval cannot be issued.

For clarification, an example of the documentation of the technical data of a ChemCar team in recent years is set at the end of this guideline. This example includes the calculations for estimating the developing reaction heat and the maximum pressure expected (see chapter 7 - 9). Please note that this example provides information only on the form and on the detail of the document but not on the content.

1. Pressure

- Pressure units:
  - Use consistent pressure units – absolute pressure \([\text{bar}_{\text{abs}}]\) oder relative pressure \([\text{bar}_g]\)

- Operating pressure:
  - What is the pressure in normal operation of the ChemCar?
    It is always necessary to document a pressure and give a description why this pressure defines normal operation.

- Maximum pressure expected:
  - What is the maximum pressure reached by reaction if pressure vessel is blocked by malfunction?
    A worst-case scenario has to be considered. Please discuss what assumptions were made for worst-case.

- Pressure test / manufacturer certificate:
  - Attach the results of the pressure tests performed or hand in a manufacturer certificate.
    When using a pressure system, a pressure test for the overall system might be necessary even if a manufacturer certificate is available. The requirements and the performance of the pressure test are specified in the ChemCar Safety Rules.
    **If not necessary for operation of ChemCar:**
    please give a comprehensible explanation why pressure test is not necessary
• Safety valve:
  - All the calculations for the design of the used safety valve (e.g. according to AD-Merkblatt A2) must be provided comprehensibly. Not only the results!
  
  **if not necessary for operation of ChemCar:**
  please give a comprehensible explanation why safety valve is not necessary

• Pressure gauge / indicator
  - Ensure, that the ChemCar has a suitable pressure gauge / indicator which has to be included in the process flowchart. It must be possible to read the internal pressure of the ChemCar at any condition (e.g. in case of breakdown of ChemCar)
  
  **if not necessary for operation of ChemCar:**
  please give a comprehensible explanation why pressure gauge / indicator is not necessary

• In accordance with the ChemCar Safety Rules, you should pay attention that the pressure content product (pressure * volume) does not exceed 50 [bar * l] as far as possible (scope of pressure equipment directive 2014/68/EU; directive 2009/104/EC "minimum health and safety requirements for the use of work equipment by workers at work"). For the calculation, you have to use the maximum pressure expected (worst-case). If the value exceeds 50 [bar * l], a consultation with the Orga-Team is recommended.

2. **Temperature**

• Temperature units:
  - Use consistent temperature units – absolute temperature [K] or relative pressure [°C]

• Maximum Temperature:
  - What is the maximum temperature expected during operation of the ChemCar?
    All calculations and their basis must be documented. Please discuss why these are reached during normal operation.

• Thermal hazard potential:
  - Are flash points or ignition points of one or more substances reached?
  - Is there any risk that thermal decomposition of one or more substances occurs? What decomposition products are formed?
  - What secondary reactions can take place?
- How big is the resulting temperature in this case?

  **Adiabatic temperature increase / decrease:**
  - Is the reaction exothermic or endothermic?
  - What reaction kinetics does the reaction have?
  - What temperature increase / decrease occurs under adiabatic conditions?
    The complete reaction of maximum quantities of the reactants must be taken into account.

  **Note:** Calculation of temperature change is always possible. Experiments will be taken as an additional source of information.
  - Results of temperature increase or decrease have to be discussed.

- Hot surfaces:
  - What temperatures can be generated at accessible surfaces?
  - Is it possible that burns due to hot surfaces can occur (guideline: \( T > 60 ^\circ C \))?
  - Is a contact protection necessary?

- Cold surfaces:
  - How cold can accessible surfaces get (by reactions or filling processes)?
  - Is it possible to get injuries due to cold surfaces, e. g. frostbites or cold burns (guideline: \( T < 0 ^\circ C \))?
  - Is a contact protection necessary?

### 3. Emissions

**Exhaust emission:**

- Are exhaust gases released before, during or after operation?
  - Which exhaust gases are released (e. g. \( \text{CO}_2, \text{CO}, \text{O}_2 \ldots \))?
- Which quantities are released in maximum (document calculations)?
- What is the maximal released substance concentration in the surrounding area?
- What are the limits for the released substance (\( \rightarrow \) toxicity\( \ldots \))?
  - Please write down the important limit values and discuss them
- Is the existing ventilation sufficient to minimize or prevent the danger from released substances?

**If necessary:** Please describe retention concept for all gases that must not be released into the surrounding.
Note:
According to the rules of ChemCar competition release of minor amounts of hydrogen resulting from a side reaction (especially parasitic reaction within an electro chemic battery) are allowed. However, this minor amount has to be calculated and safety issues have to be assessed while creating the safety concept. If the data concerning the formation of hydrogen is incomplete use comprehensible assumptions which have to be presented in detail in the safety concept.

- Noise emission:
  - What is the maximum noise level expected during operation?
  - Is it possible that injuries / impairments occur due to noise exposure (performer and viewers)?

4. Procedure

- Filling / dosing:
  - How is the reactor filled?
  - How are the educts dosed?
  - Is a wrong filling or wrong dosing possible?
  - What consequences can a wrong filling / dosing have?

- Leakage / unintended release:
  This refers to a leakage during operation – competition in the hall.
  - What dangers could be caused by leakage or accidental release?
  - What measures should be taken in case of a leak or an unintentional release (especially liquid leakages)?
  - Is there a retention concept, e. g. collecting basins?
  - What kind of personal protective equipment is necessary in case of unintended release?

Note:
The handling of unintended release or leakage during work at the ChemCar in preparation room has to be described also.

- Mechanical function:
  - How is the force transmitted?
  - What happens during a mechanical blockage? For example, the blocking of wheels? Is it possible that a hazardous situation can develop?
• Intended mode of operation
  - How is the intended mode of operation defined?
  - How is it planned that the ChemCar – after executing the starting action before the run – will be provided with energy, starts to move, moves on (running) and finally stops?
  - How is the material flow during intended mode of operation?

• Emergency Shutdown
  - Is there an emergency shutdown mechanism?
  - How does this mechanism work? Description of manual function.

5. Documentation

• Basic documents:
  - A detailed functional description of the ChemCar
  - A photo or drawing of ChemCar (even unfinished ChemCar as status quo) – please add date of picture and state of assembly of ChemCar OR show separate part / steps of construction
  - A block flow diagram of the process
  - P&ID of the ChemCar. Pay attention to completeness (piping, inscriptions etc.). Please keep in mind the difference to a block flow diagram
  - Safety Data Sheets of all existing substances (both used substances and produced) – please keep in mind that SDS have to be up to date (ideally not older than 2 years!)
  - H- and P-phrases in written form (not only abbreviations)
  - Summary of all used substances with quantities in a register of hazardous substances

• Operating principle:
  - Description of the relevant system components (turbine, safety-bags etc.) and how they work

• Operating instructions:
  - Operating instructions according to TRGS 555 and GefStoffV § 14 for used reactants, products and potential auxiliaries. In the operating instructions the risks (explosive, oxidizing, toxic etc.), preventable conditions, transport, handling and disposal of the substance must be explained briefly. The minimum required personal protective equipment should be apparent from the operating instructions. An example of an operation instruction
is shown in chapter 9.
► **A Safety Data Sheet is no operation instruction** but can be used as source of information in preparation of an operation instruction (see. Appendix to TRGS 555)!!

- **Reaction Equation:**
  - Document the complete (!) reaction equation, including all side reactions and intermediates

- **Calculations:**
  - All calculation methods must be documented (maximum temperature, maximum pressure, temperature increase etc.). Not only the results.
  
  If an Excel-Sheet is used please pay attention to confirmability of the documentation!

- **Suitability of the material:**
  - Are used materials suitable?
  - Is corrosion or embrittlement of material possible, caused by used or formed substances?
  - Are the used materials suitable for the existing temperature ranges?

**Note:**
All components of the ChemCar must be considered in this context. For all components that may come into contact with substances / chemicals (educts, intermediate products, products) a material suitability must be proved. This means that it has to be clarified if the utilised materials could interact with the substances / chemicals under operating conditions. In particular, damages or malfunctions of the ChemCar must be taken into consideration, i.e. is a retention of released substances ensured? Is it possible that released substances interact with the retention equipment and affect the retention function significantly?

**The proof of the material compatibility (manufacturer specifications, laboratory tests etc.) especially with the chemicals** (→ educts, products AND intermediate products) **is an essential part of the safety concept.**

If you hand in lists of material suitability these should be highlighted clearly. It is not necessary to hand in a complete list. The front page and the page with the marked passage are sufficient.

6. **Risk assessment**

The purpose of a risk assessment is the coverage of the intended use and any faults. The consequences of a disturbance have to be referred to the specific application. A reference to the Safety Data Sheet (general application) is not enough!
In addition to resulting hazards (e. g. explosion risk) caused from the used substances those caused by material properties (glass containers ► splinter protection) or components (fast rotating components ► cover) should be considered also.

**Example for a risk assessment (Safety-Analysis Form):**

<table>
<thead>
<tr>
<th>Sequence of Steps</th>
<th>Potential Hazards</th>
<th>Procedure to Control Hazard</th>
<th>PPE or Equipment Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency shut-down</td>
<td></td>
<td>Procedure A (z. B. stop educts supply, Opening of the safety valve)</td>
<td>PPE A, B, C (z. B. safety glasses, gloves and gowns)</td>
</tr>
<tr>
<td>Start-Up Procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Run Time Procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shutdown Procedure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleanup / Waste Disposal</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Example for a hazardous substances register:

General Notes for making the safety concept:

- For preparation of the safety concept (including a risk assessment) it is necessary to answer the questions and remind the hints given at points 1. – 6. of this document. It is a non-exhaustive enumeration, what means hazards resulting from your ChemCar in special have to be assessed and discussed by yourself.
- The safety concept that includes the risk assessment has to be done as free text
Example: Calculation of the thermal hazard potential

To calculate the power, which is needed to absolve the required distance in addition of a given weight, this calculation chart is used.

The ideal gas law is used to charge the required amount of released gas (here: CO₂) to run a piston engine. The application quantity is given by the stoichiometry of the reaction. The correction is made by experimental data. The heat capacity and the density is assumed as the value of water, because all educts are in liquid form or dissolved in this phase.
8. Example for the design of a safety valve

Resource: AD2000-A2: SAFETY VALVE

<table>
<thead>
<tr>
<th>Nomination</th>
<th>Unit</th>
<th>Formula / Symbol</th>
<th>Value</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening Pressure</td>
<td></td>
<td>1 barₖ</td>
<td>d₀ = 18 mm, α = 0.54</td>
<td></td>
</tr>
<tr>
<td>Item Number</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference</td>
<td></td>
<td>A D2000-A2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nomination</td>
<td>Unit</td>
<td>Formula / Symbol</td>
<td>Value</td>
<td>Remark</td>
</tr>
<tr>
<td>Surroundings Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Pressure</td>
<td>Pa</td>
<td>Pᵥₑ</td>
<td>1,01E+05</td>
<td></td>
</tr>
<tr>
<td>Internal Pressure</td>
<td>Pa</td>
<td>Pᵥ₀</td>
<td>2,01E+05</td>
<td>1 barₖ</td>
</tr>
<tr>
<td>Temperature</td>
<td>K</td>
<td>T</td>
<td>293,15</td>
<td></td>
</tr>
<tr>
<td>Passage Surface</td>
<td>m²</td>
<td>A₀</td>
<td>0,0003</td>
<td>d = 18 mm</td>
</tr>
<tr>
<td>Effluent Number</td>
<td>-</td>
<td>α</td>
<td>0,54</td>
<td></td>
</tr>
<tr>
<td>Thermodynamic Data</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Substance Notation</td>
<td></td>
<td>28,2 Vol.% NH₃</td>
<td>mixture</td>
<td></td>
</tr>
<tr>
<td>Molar Mass</td>
<td>kg/mol</td>
<td>M</td>
<td>not necessary</td>
<td></td>
</tr>
<tr>
<td>Compressibility</td>
<td>-</td>
<td>Z</td>
<td>0,889</td>
<td></td>
</tr>
<tr>
<td>Isoentropic Exponent</td>
<td>-</td>
<td>κ</td>
<td>1,4</td>
<td></td>
</tr>
<tr>
<td>Results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal Mass Flow</td>
<td>kg/s</td>
<td>( \dot{m} = \alpha \cdot A₀ \cdot \psi \cdot \sqrt{2 \rho₀ \cdot P₀} )</td>
<td>2,26E-01</td>
<td></td>
</tr>
<tr>
<td>Maximal Mass Flow</td>
<td>kg/h</td>
<td>( \dot{V}_N = \frac{\dot{m}}{\rho N} )</td>
<td>8126,1807</td>
<td></td>
</tr>
<tr>
<td>Maximal Volume Flow</td>
<td>Nm³/s</td>
<td>( V_N )</td>
<td>1,38E-01 Standard Volume</td>
<td></td>
</tr>
<tr>
<td>Maximal Volume Flow</td>
<td>Nm³/h</td>
<td>( V_N )</td>
<td>497,014</td>
<td></td>
</tr>
<tr>
<td>Flow Profile</td>
<td>-</td>
<td>Critical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculation Part</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gas Density</td>
<td>kg/m³</td>
<td>( \rho₀ = \frac{P \cdot M}{R \cdot Z \cdot T} )</td>
<td>28,531</td>
<td></td>
</tr>
<tr>
<td>Standard Gas Density</td>
<td>kg/m³</td>
<td>( \rho N = \frac{101300 \cdot [\rho₀] \cdot M}{R \cdot 273,15 \cdot [K]} )</td>
<td>1,635</td>
<td></td>
</tr>
<tr>
<td>Pressure Relation In/External</td>
<td>-</td>
<td>( \eta₀ = \frac{Pₑ}{\rho₀} )</td>
<td>0,503</td>
<td></td>
</tr>
<tr>
<td>Critical Pressure Relation</td>
<td>-</td>
<td>( \eta_{crit} = \left( \frac{2}{\kappa+1} \right)^{\kappa-1} )</td>
<td>0,528</td>
<td></td>
</tr>
<tr>
<td>Pressure Relation</td>
<td>-</td>
<td>( \eta = \begin{cases} \eta_{crit} &gt; \eta₀ \rightarrow \eta_{crit} \ \eta_{crit} \leq \eta₀ \rightarrow \eta₀ \end{cases} )</td>
<td>0,528</td>
<td></td>
</tr>
<tr>
<td>Effluent Function</td>
<td>-</td>
<td>( \psi = \left( \frac{\kappa}{\kappa-1} \cdot \left( \eta \cdot \left( 1 - \eta \cdot \frac{\kappa-1}{\kappa} \right) \right) \right)^{\kappa-1} )</td>
<td>0,484</td>
<td></td>
</tr>
</tbody>
</table>
9. Example: instruction manual according to TRGS 555/GefStoffV § 14

<table>
<thead>
<tr>
<th>HAZARDOUS SUBSTANCE / OPERATIONS / WORKPLACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrochlorid Acid, from 10% to 25%</td>
</tr>
</tbody>
</table>

**HAZARDS FOR HUMEN AND ENVIRONMENT**
- Possibly corrosive against metal (H210)
- Causes skin irritation (H315)
- Causes heavy eye irritation (H335)
- May cause sensitization and induction of an allergic reaction (H318)
- Possible respiratory or skin contact can cause health damages. Irritates the air passages, eyes and skin. Can cause damage to the gastrointestinal tract. Temporary cough, sore throat and rash in skin disorder. Possibly damaged lungs, eyes, teeth, kidneys, gastrointestinal tract and lymphatic tissue.

**Safeguarding and Behavioural Rule**
- Activate the aspiration and work in its support by emission of mapping or noise. Do not leave bundles and burnola in areas. Avoid splashing and irritation by filling and dressing. Hold reactive substances off and add them carefully. Add the water first and afterwards the acid by slow dripping. (Control Temperature Use acid resistant equipment. Use always the protective clothing.
- Do not sniff, drink, smoke or sniff. Avoid inhalation of damping and aerosol. Avoid contact with eyes and skin. Clean hands and other contaminates by putting wet and non-flammable water and soap. Pour the product residues from the skin, clean and liberate the concerned skin. Do not wear hard or airy decoration. Separately store street and work clothes. Rapidly shift contaminant and soaked work clothes use separately cleaning rag and separator for skin and machines.
- Follow the storage conditions.
- M-im employment conditions.

**Supplies at workplace:**
- Eye protection: Using frame glasses with side protection by monitoring activity. (Lid) shaped glasses by risk of splashing
- Hand protection: Gloves made of a suitable material in response to the activity. It is preferable to wear cotton made under gloves under the protection glove.
- Respiratory protection: Consider the gestation periods of the protection, smoking is prohibited by wearing of the longer term.
- Breathing protection: Combination filter F2 (yellow/white) or B3 (grey/white/yellow/white)
- Body protection: Wearing of a protective apron by diluting or bottling.

**BEHAVIOUR BY EMERGENCY**
- Contacting the emergency by calling the number 112
- Preventing intrusion in ground, water and carbonation.
- Distancing containers, excluding emergency routes. Ask fire service.

**FIRE SERVICE**
- EMERGENCY CALL 110

**EMERGENCY CALL 110**
- By the first aid measures:
  - Life saving emergency measures have to perform: Artificial respiration, cardiopulmonary resuscitation or shock control. Stabilize the covering wounds. Read the body and protecting for heat loss.
  - After eye contact: Immediately, it has to be rinsed for minimum 10 minutes by opened eye and protected uninvolved eye.
  - After skin contact: Taking off contaminated clothes, even under wear and shoes, wearing personal protection utilities. Rinsing the skin with much water.
  - After inhalation: Take the contaminated areas. Fresh-air supply by breathing of fresh air or ventilation. Using decontamination devices (self protection). Immediately, even by missing signs of diseases, using a sterile (DOSER device) for inhaling (inspiral form). Dosage, kind of use and further treatment according to medical prescription.
  - After swallowing: Directly flush out the mouth. Drink water in small gaps.

**FIRST AID**

**PROPER DISPOSAL**
10. References

1. https://www.gischem.de  Gefahrstoffinformationssystem Chemikalien der BGRCI und der BGHM

2. https://gestis.dguv.de/  GESTIS-Stoffdatenbank: Gefahrstoffinformationssystem der Deutschen Gesetzlichen Unfallversicherung


