Design of Safety Valves
Design standard: ASME VIII / API 520
Objectives of this Presentation. Design of Safety Valves: ASME VIII / API 520.

The objective of the presentation is to show the design of safety valves in compliance with ASME VIII / API 520

- Standard specifications for the design of safety valves
- Formulas for the design of safety valves
- Factors Influencing the stability in operation
National and international standards. For calculation of safety valves.


Calculation levels for safety valves

- ISO 4126-1
- AD 2000 – Merkblatt A2
- API 520
- ASME VIII

Calculation levels of inlet pressure loss and back pressure

- ISO 4126-9
- AD 2000 – Merkblatt A2

Chapter 7 + 9

Chapter 6
National and international standards. For calculation of safety valves.


- ISO 4126-1 must be applied in the European region for size determination of safety valves
- TRBS is not yet available for specification of the safety valve

Size determination

- There is no effect on the capacity and function up to a pressure loss of 3%
- Pressure losses >3% must be taken into account in the capacity calculation. The operation may be affected.

Inlet pressure loss
What impact does this have on the user?


- Effect on the capacity taking the $p_{ao}/p_o$ curve into consideration
- This ratio is observed for absolute pressures.

- Capacity minimisation must also be taken into consideration for low set pressures.

- $p = 0.03$ bar g (set pressure)
- $p_{ao} = 1.013$ bar a (ambient pressure)
- $p_o = (0.3$ barg $+ 0.1$ barg $+ 1.013$ bar a) (pressure in the system to be secured)
- $p_{ao} / p_o = 1.013$ bar a / $(0.3$ barg $+ 0.1$ barg $+ 1.013$ bar a) = 0.72
- $>> K_b = 0.81$
What parameters are important for the design and how are they related?

- **Coefficient of discharge \( \alpha_{w} \):**
  the rated coefficient of discharge from component testing (often also referred to as \( \alpha_{d} \))

- **Orifice area \( A_{0} \):**
  actual orifice area

- **Substance information**
  medium-dependent substance data

- **Operating data:**
  state parameters like pressure and temperature
## Coefficient of discharge and rated coefficient of discharge.

1. Objectives  
2. Codes and standards  
3. Design  
4. Inlet pressure  
5. Back pressure

### German Code

<table>
<thead>
<tr>
<th>VdTÜV Merkblatt SV 100, § 3.3.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \alpha = \frac{q_{\text{measured}}}{q_{\text{theoretical}}} ]</td>
</tr>
<tr>
<td>[ \alpha_w = 0.9 \times \alpha ]</td>
</tr>
</tbody>
</table>

### American Code

<table>
<thead>
<tr>
<th>ASME-Code Sec.VIII, Div. 1, UG-131 (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ K_d = \frac{q_{\text{measured}}}{q_{\text{theoretical}}} ]</td>
</tr>
<tr>
<td>[ K = 0.9 \times K_d ]</td>
</tr>
</tbody>
</table>

- \( q_{\text{measured}} \): actual measured \( q_m \)  
- \( q_{\text{theoretical}} \): calculated \( q_m \)  
- \( \alpha \) or \( K_d \): coefficient of discharge  
- \( \alpha_d \) or \( K \): rated coefficient of discharge  
- 0.9: correction factor
Differentiation of media.


Medium

- Steams/ gasses
  - Subcritical
  - Supercritical
- Liquids
  - Low viscosity
  - High viscosity
  - Saturated steam
  - Superheated steam
  - Liquid phase
  - Gaseous Phase
- Steam
  - Two-phase flow
Coefficient of discharge and rated coefficient of discharge.


<table>
<thead>
<tr>
<th></th>
<th>Gasses / steams</th>
<th>Liquids</th>
<th>Saturated steam</th>
<th>Superheated steam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set pressure $p_{set}$</td>
<td>psig</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Back pressure $p_a$</td>
<td>psig</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Temperature $T$</td>
<td>[°C]</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Mass flow* $q_m$</td>
<td>[kg/h]</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Volumetric flow rate* $q_v$ (while operating)</td>
<td>[m³/h]</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Volumetric flow rate* $q_v$</td>
<td>[Nm³/h]</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overpressure $c$</td>
<td>[%]</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Real gas factor $Z$</td>
<td>[-]</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molar mass $M$</td>
<td>[kg/kmol]</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isentropic exponent $k$</td>
<td>[-]</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density $\rho$</td>
<td>[kg/m³]</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kinematic viscosity $\nu$</td>
<td>[m²/s]</td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Denotes units for gases and steam only.
Design for gases/steam as per ASME VIII.


\[ A = \frac{W}{C \cdot K \cdot P} \cdot \sqrt{\frac{Z \cdot T}{M}} \]

- **Code**: A = \( \frac{W}{C \cdot K \cdot P} \cdot \sqrt{\frac{Z \cdot T}{M}} \)
- **Medium data**: medium data – components
- **Process data**: process data – components
- **Flow coefficient**: flow coefficient – components
Design for gasses/steam as per API 520 vs. ASME VIII.


**API**

\[
A = \frac{W}{C \cdot K_d \cdot P_1 \cdot K_b \cdot K_c} \cdot \sqrt{\frac{T \cdot Z}{M}}
\]

**ASME**

\[
A = \frac{W}{C \cdot K \cdot P_1} \cdot \sqrt{\frac{T \cdot Z}{M}}
\]

**ASME/API**

\[
A_{ASME} \times K \geq A_{API} \times K_d
\]
### Objectives
- Actual orifice area
- Mass flow
- Functional isentropic exponent
- Rated coefficient of discharge
- Relieving pressure
- Temperature
- Molar mass
- Real gas factor

### Codes and standards
- ASME VIII

### Design
- Inlet pressure
- Back pressure

### Inlet pressure

\[
A = \frac{W}{C \cdot K \cdot P_1} \cdot \sqrt[3]{\frac{T \cdot Z}{M}}
\]

### ASME VIII

<table>
<thead>
<tr>
<th>Actual orifice area</th>
<th>A [inch²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass flow</td>
<td>W [lb/h]</td>
</tr>
<tr>
<td>Functional isentropic exponent</td>
<td>C [-]</td>
</tr>
<tr>
<td>Rated coefficient of discharge</td>
<td>K</td>
</tr>
<tr>
<td>Relieving pressure</td>
<td>P₁ [psi g]</td>
</tr>
<tr>
<td>Temperature</td>
<td>T [°F]</td>
</tr>
<tr>
<td>Molar mass</td>
<td>M [kg/kmol]</td>
</tr>
<tr>
<td>Real gas factor</td>
<td>Z [-]</td>
</tr>
</tbody>
</table>
Orifices as per API RP 526 and ASME VIII (Steam and Gasses).


(Type 526, orifice and discharge coefficient K individual for LESER types)

<table>
<thead>
<tr>
<th>Designation</th>
<th>API Effective Orifice Area [sq in]</th>
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<tr>
<td>G</td>
<td>0.503</td>
<td></td>
<td>0.43</td>
<td>0.616</td>
</tr>
<tr>
<td>H</td>
<td>0.785</td>
<td>0.975</td>
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<tr>
<td>J</td>
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<td></td>
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Design of safety valves – ASME VIII / API 520 | LESER GmbH & Co. KG | 01.06.2018 | Rev. 00 | 13/27
Design for steam as per API 520 vs. ASME VIII.


**API**

\[
A = \frac{W}{51.5 \cdot P_1 \cdot K_d \cdot K_b \cdot K_c \cdot K_N \cdot K_{SH}}
\]

**ASME**

\[
A = \frac{W}{51.5 \cdot K \cdot p_0 \cdot K_N \cdot K_{SH}}
\]

**ASME/API**

\[
A_{\text{ASME}} \times K \geq A_{\text{API}} \times K_d
\]

Design of safety valves – ASME VIII / API 520 | LESER GmbH & Co. KG | 01.06.2018 | Rev. 00 | 14/27
Design for saturated steam as per ASME VIII.

1. Objectives
2. Codes and standards
3. Design
4. Inlet pressure
5. Back pressure

**ASME VIII**

\[
A = \frac{W}{51.5 \cdot K \cdot p_0 \cdot K_N \cdot K_{SH}}
\]

- Actual orifice area
- Pressure in pressure chamber
- Mass flow
- Rated coefficient of discharge
- Napier correction factor
- Superheated steam correction factor

A [in²]  
p₀ [bar abs]  
W [lb/h]  
K  
K_N  
K_SH
Orifices as per API RP 526 and ASME VIII (Saturated Steam).

1. **Objectives**
2. **Codes and standards**
3. **Design**
4. **Inlet pressure**
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API Effective Orifice Area \([\text{sq in}]\)

API Coefficient of discharge Kd = 0.975

ASME Actual Orifice Area \([\text{sq in}]\) = \(\text{Designation} \times 0.801\)

**Notes:**
- Orifices as per API RP 526 and ASME VIII (Saturated Steam).
- Design of safety valves – ASME VIII / API 520 | LESER GmbH & Co. KG | 01.06.2018 | Rev. 00 | 16/27
**API sizing vs. ASME VIII sizing.** (Liquids).

1. **Objectives**
2. **Codes and standards**
3. **Design**
4. **Inlet pressure**
5. **Back pressure**

### API

\[
A = \frac{W}{38 \cdot K_d \cdot K_W \cdot K_c \cdot K_V} \cdot \sqrt{\frac{1}{p_1 - p_2}}
\]

### ASME

\[
A = \frac{W}{2407 \cdot K \cdot \sqrt{\mu_0 - p_{a0}}} \cdot w
\]

### ASME/API

\[A_{ASME} \times K \geq A_{API} \times K_d\]
Design equation for liquids as per API 520.

\[ A = \frac{W}{38 \cdot K_d \cdot K_w \cdot K_c \cdot K_v} \cdot \sqrt{\frac{G}{p_1 - p_2}} \]

### API

- Actual orifice area
- Pressure in pressure chamber
- Back pressure
- Mass flow
- Specific density
- Rated coefficient of discharge
- Correction factor for bellows
- Correction factor for bursting disc
- Correction factor for viscosity

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>in²</td>
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<tr>
<td>p₁</td>
<td>psi a</td>
</tr>
<tr>
<td>p₂</td>
<td>psi g</td>
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<td>Q</td>
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Orifices as per API RP 526 and ASME VIII (Saturated Steam).


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</tbody>
</table>
Inlet pressure loss. Influencing factors.


\[ p_2 = p_1 \]
\[ \Delta p = 0 \]

Valve is closed

\[ p_2 = p_1 - \Delta p \]
\[ \Delta p > 0 \]

Valve is open
Inlet pressure loss. Standards and bodes.


- (Type 526, orifice aA maximum pressure loss of 3% between the vessel and the safety valve is permissible for the most common international standards and codes.

- **API 520 Part II (08.2003), 4.2.2**
  “When a pressure relief valve is installed on a line directly connected to a vessel, the total non-recoverable pressure loss between the protected equipment and the pressure relief valve should not exceed 3 percent except as permitted in 4.2.3 for pilot-operated pressure relief valve.”
Calculation. (Only calculated as per AD and ISO).


\[ \Delta p = (\lambda \cdot \frac{l}{d} + \sum \zeta) \cdot \frac{\rho}{2} \cdot w^2 \]

- \( \lambda \) = Pipe friction coefficient (pipeline)
- \( l/d \) = Length and diameter of a pipe
- \( \zeta \) = Friction coefficient (components)
- \( \rho \) = Density
- \( w \) = Speed
Inlet pressure loss.

The following *measures prevent malfunctions* that are caused by an inadmissible *inlet pressure loss*:

- **Reduction of the flow rate through**
  - increasing the pipe diameter
  - reducing the mass flow through a smaller valve
  - reducing the mass flow through a lift stopper
  - reducing the mass flow through an O-ring-damper

- **Reduction of the flow rate through**
  - shorter inlet pipeline
  - low-resistance connection to the vessel
Inlet pressure loss. (Only calculated as per AD and ISO).

Reduction of the flow rate is more effective than reduction of the flow resistance

\[ \Delta p = (\lambda \cdot \frac{l}{d} + \sum \zeta) \cdot \frac{\rho}{2} \cdot w^2 \]

Reduction of flow resistance

Reduction of the flow rate (w)

Reduction of the pressure loss (%)
Back pressure. Definition.


Exists only in the outlet while the safety valve blows off. It is dependent on the flow loss in the discharge line.

Back pressure = built-up back pressure – external pressure

Built-up back pressure

External back pressure

Constant

Variable

Exists permanently in the outlet system. The external back pressure is dependent on the blow-off of the safety valve.
The following measures prevent malfunctions resulting from the back pressure:

- **Constant back pressure**
  - settings to differential set pressure (CDTP)
  - use of stainless steel bellows

- **Variable back pressure**
  - use of stainless steel bellows
Design of Safety Valves
Thank you for your attention.