Pressure Safety Valves
Some considerations on their use & sizing

the Dynaflow Research Group lectures
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Jean-Paul Boyer
Pressure Safety Valves

- Useless valves...
  - No need for process
  - Never used (hope!)
  - High up, forgotten

- But big impact
  - Can limit production
  - Can have high life-cycle cost
  - Can cause havoc
Flow Sizing

The All Important factor, KA
flow coefficient ‘K’ times flow area ‘A’

Gases:

\[ W = C_{b} K_{A} P_{1} K_{b} \sqrt{\frac{M}{T_{1}Z}} \]

Liquids:

\[ W = K_{A} K_{W} K_{V} \sqrt{\rho \left( P_{1} - P_{2} \right)} \]

(need some factors depending on units used)
The KA Factor

- Area or Flow Coefficient alone not enough
  - Capacity is what matters
    - Manufacturer cannot claim capacity higher than the certified capacity
    - But he can claim a lower one (so called ‘safe’)

- It all relates to $KxA$
  - Other factors $K_b$, $K_w$, $K_v$… will depend on service conditions
  - KA defines the particular valve, fixes its capacity
    - Certification (e.g. ASME with National Board)
KA Factor

- Long ago…
  - Certified capacity = actual capacity
  - API Std 526 reflected actual valve values
- In 1962, ASME VIII revised ‘K’ to include
  - 10% safety factor: certified $K = 0.9 \times K_{\text{actual}}$
  - National Board allowed deviations between certified values and published values as long as:

  Published capacities $\leq$ Certified Capacities
  Or
  Published $KA \leq$ Certified $KA$
KA Factor

- During certification
  - A is measured
    - Smallest section in the flow path (throat)
  - Actual flow is compared to theoretical flow through perfect nozzle (K=1)
    - $\frac{W_{\text{actual}}}{W_{\text{theor}}} = K_{\text{actual}}$
    - $K = 0.9 \times K_{\text{actual}}$
KA Factor

- Since 1962, most manufacturers have
  - Overstated K
  - Understated A

- Example on ‘Q’ orifice on gas
  - API Std 526: A = 11.05 in², K=0.975, KA=10.77

<table>
<thead>
<tr>
<th></th>
<th>Certified A</th>
<th>Certified K</th>
<th>KA</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crosby JOS</td>
<td>12.47</td>
<td>0.865</td>
<td>10.79</td>
<td>+0.2%</td>
</tr>
<tr>
<td>AG POSV</td>
<td>18.29</td>
<td>0.627</td>
<td>11.47</td>
<td>+6.5%</td>
</tr>
<tr>
<td>‘X’</td>
<td>12.85</td>
<td>0.855</td>
<td>10.99</td>
<td>+2%</td>
</tr>
<tr>
<td>‘Y’</td>
<td>12.26</td>
<td>0.878</td>
<td>10.76</td>
<td>0%</td>
</tr>
</tbody>
</table>
Safety Valve Sizing

- Preliminary sizing
  - API RP 520 part 1, clause 5.2.1:
    «PRV’s may be initially sized... [using] effective coefficients of discharge and effective areas which are independent of any specific valve design. In this way, the designer can determine a preliminary PRV size.»
  - Effective areas → API Std 526, D through T
  - Effective coefficients → API RP 520
    - Gases, $K=0.975$
    - Liquids, $K=0.650$
    - 2-phase, $K=0.850$
Safety Valve Sizing

- Final, using manufacturer’s data
  - API RP 520 part 1, clause 5.2.5:
    «When a specific valve design is selected... the rated capacity of that valve can be determined using the actual orifice area, the rated coefficient of discharge... The actual orifice area and the rated coefficient of discharge shall always be used to verify the actual capacity of the PRV.»
  - Actual areas ➔ certified (e.g. ASME, NB-18)
  - Rated coefficients ➔ certified
National Board NB-18 ‘Red Book’

- NB-18 viewed on line or downloaded
- All data on each and every valve (& RD) certified per ASME codes (I, III & VIII)

<table>
<thead>
<tr>
<th>Certification Number</th>
<th>Design Series or catalog number</th>
<th>Type Classification</th>
<th>Capacity Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>K = Kd x 0.90</td>
</tr>
</tbody>
</table>

**K = Kd x 0.90**

<table>
<thead>
<tr>
<th>Inlet Size</th>
<th>Outlet Size</th>
<th>Flow Area</th>
<th>Orifice [designator] diameter</th>
<th>Lift</th>
<th>Set Pressure Range</th>
<th>Media</th>
<th>Code Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 1.5 NPS</td>
<td>2 NPS</td>
<td>0.205 sq in</td>
<td>[D] 0.827 in</td>
<td>0.079 in</td>
<td>15 - 15000 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>1 - 1.5 NPS</td>
<td>2 NPS</td>
<td>0.356 sq in</td>
<td>[E] 0.827 in</td>
<td>0.137 in</td>
<td>15 - 15000 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>1.5 NPS</td>
<td>2, 3 NPS</td>
<td>0.831 sq in</td>
<td>[C] 1.079 in</td>
<td>0.241 in</td>
<td>15 - 10600 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>2 NPS</td>
<td>3 NPS</td>
<td>0.85 sq in</td>
<td>[G] 1.440 in</td>
<td>0.191 in</td>
<td>15 - 15000 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>2 NPS</td>
<td>3 NPS</td>
<td>1.312 sq in</td>
<td>[H] 1.440 in</td>
<td>0.295 in</td>
<td>15 - 15000 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>2 NPS</td>
<td>3 NPS</td>
<td>2.132 sq in</td>
<td>[J] 2.151 in</td>
<td>0.323 in</td>
<td>15 - 10600 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>2 NPS</td>
<td>4 NPS</td>
<td>3.043 sq in</td>
<td>[K] 2.151 in</td>
<td>0.461 in</td>
<td>15 - 10600 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
<tr>
<td>4 NPS</td>
<td>6 NPS</td>
<td>4.729 sq in</td>
<td>[L] 4.456 in</td>
<td>0.477 in</td>
<td>15 - 10600 psi</td>
<td>Air</td>
<td>VIII Div. 1</td>
</tr>
</tbody>
</table>
Sizing Safety Valves

- Sizing ‘per API’ does not imply using API standard orifices
- API RP 520 (contains sizing) does not list the orifices (listed in API Std 526)
- API RP 520 recommends to use manufacturer’s data for final sizing

- ASME (National Board) does not bother what area or coefficient is used as long as:
  \[ K \times A \leq \text{Actual value} - 10\% \]
Reaction Force

- At relief, the jet out of the valve creates an opposite force, a thrust
  - \( F_d = c_2 \cdot W \)

- Added to static force from pressure at outlet flange
  - \( F_s = (P_2 - P_{atm}) \cdot A_2 \)
## Reaction Force

### State of Fluid

<table>
<thead>
<tr>
<th>State of Fluid</th>
<th>Total Reaction Force, daN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas / Vapour</strong></td>
<td></td>
</tr>
<tr>
<td>Choked</td>
<td>( \frac{W}{279.1} \sqrt{\frac{T_1 k}{M (k+1)}} + p_2 A_2 )</td>
</tr>
<tr>
<td>Unchoked</td>
<td>( \frac{W}{279.1} \sqrt{\left( \frac{k}{k-1} \right) \left[ 1 - \left( \frac{P_2}{P_1} \right)^{\frac{k-1}{k}} \left( \frac{T_1}{M} \right) \right]} + p_2 A_2 )</td>
</tr>
<tr>
<td><strong>Liquid</strong></td>
<td></td>
</tr>
<tr>
<td>Unchoked</td>
<td>( \frac{W^2}{1.296 \times 10^7 GA_2} + p_2 A_2 )</td>
</tr>
<tr>
<td><strong>Two-Phase</strong></td>
<td></td>
</tr>
<tr>
<td>Choked</td>
<td>( \frac{v_1 W^2}{12960 A_2} \left[ \omega \left( \frac{P_1}{P_2} - 1 \right) + 1 \right] + p_2 A_2 )</td>
</tr>
<tr>
<td>Unchoked</td>
<td></td>
</tr>
</tbody>
</table>

1 = Inlet, stagnation conditions  2 = Outlet conditions

- \( W \), flow, kg/hr
- \( T_1 \), inlet temp, °K
- \( k \), ratio specif. heats
- \( M \), molar mass
- \( p_2 \), outlet pressure, barg
- \( A_2 \), outlet section, cm²
- \( G \), relative density
- \( v_1 \), specif volume, m³/kg
- \( P_1 \), relieving pressure, barA
- \( P_2 \), outlet pressure, barA
Reaction Force

- Capacity W to consider:
  - Pop action POSV and Spring Loaded SV
    - Safety valve full capacity (actual = rated/0.9)
      - Instantaneous flow rate on opening is the maximum capable flow of the valve
  - Modulating action POSV
    - Required capacity
  - Rupture Discs and Buckling Pin Valves
    - Required capacity

- Same for noise or back-pressure calculations
  (Ref ISO23251/API521, 7.2.1 table12)
Discharge Bracing
Tailpipe to Atmosphere

- Bending moment on riser between equipment and safety valve
Tailpipe to Atmosphere

- Minimises bending moment at base of inlet riser
Do and Don’t?
Reaction Force

- Dual Outlet valves
  - no stress on the valve
Braced Dual Outlet POSV
Double exhaust
Discharge to Piped System
Pipe Strains

- Discharge piping should be
  - independently supported
  - free from misalignment
  - taking care of expansion/contraction, thermal loading

- Pipe strains can cause
  - misalignment of valve internals:
    - leakage
    - seizure
  - stress on valve body
    - cracks in body casting
Noise through Safety Valves

- Aim of SV is to drop pressure as much as possible. $\Delta P$ very high, high amount of dissipated energy, a lot of it into noise
  - SV are noisy
- SV must have no pressure recovery to do their job
- Due to turbulences inside the body bowl, gas velocity at outlet is most often super-sonic
Pressure Drop in Safety Valves

- Pressure continues to drop after nozzle in the body bowl, with shock-waves
Noise through Safety Valves

- Basic formula for stack tip (ISO23251/API521)
  - 30 m of tip
  - Open outlet

\[
L_{(30)} = L_{(fig)} + 10 \log \left( \frac{1}{2} W c^2 \right)
\]

\[
c = 91.2 \sqrt{\frac{kT}{M}}
\]

Acoustic Efficiency of Choked Jet

\[
L_{(d)} = L_{(30)} - 20 \log \left( \frac{d}{30} \right)
\]
Noise through Safety Valves

- Control valves standards (IEC 534-8-3, ISA 75-07, VDMA 24-422…)
  - Accuracy for 0.3 to 0.8 Ma outlet
  - Safety valves: outlet Ma >> 1
- Safety valves normally designed to withstand stress
  - Potential problems for outlet piping
    - Expander, reduce speed
    - Avoid accident close to the valve outlet (new choke points)
A Dual Answer

- Exhaust to atmosphere: angle-cut tail pipe
  - Reduced noise
  - Reduced reaction force
  \[ A_{\text{exit}} \Rightarrow c_{\text{exit}} \Rightarrow F_d \]
  - and noise…
Back Pressure

(back pressure)

Inlet

THE PRESSURE AT THE OUTLET OF A PRESSURE RELIEF DEVICE.
Discharge Safety Valve is Open and Flowing

- Built-Up BP is caused by pressure drop in discharge piping
Conventional Spring Valve

Lift vs Built-Up Back Pressure

% of Full Rated Lift

Built-Up BP in % of Set Pressure
Lift vs Built-Up Back Pressure

% of Full Rated Lift

Conventional Spring Valve

Balanced Spring Valve

Correction factor \((K_b, K_w)\)
Reduced Capacity

Built-Up BP in % of Set Pressure

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Superimposed Back Pressure

Possible Pressure Source → To Flare, Recovery System, or Atmosphere

Possible Pressure Source → Discharge Header System

Possible Pressure Source → BPs

Possible Pressure Source → PRV (Closed)

Protected System

Constant Purge?
Constant Back-Pressure

- Constant Back-Pressure
  - valve discharge into a system at a constant pressure
  - pump suction, steam tank, ...

- Always superimposed
Variable Superimposed BP

- Variable Super-Imposed
  - Valve discharge into a system at a variable pressure which exists when valve is closed
  - Flare system, ...

Closed

Opened & Flowing

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Superimposed Backpressure

- Exists even when the considered valve is closed
  - It can affect the set pressure of this valve
  - This valve may open at a pressure higher than the design pressure of the equipment
Conventional Valve

- Downwards spring force (constant)
  \[ F_d = \frac{K}{L} \]

- Upwards fluid force (variable)
  \[ F_u = P \times A \]

- Set: \( F_d = F_u \)
Conventional Valve

- Superimposed BP adds itself to the spring force:
  \[ F_d = \frac{K}{L} + BPx_A \]

- Set: \( F_d = F_u \)
  \( (F_u = P \times A) \)

- Actual Set: Spring set + BP
Superimposed Variable BP

- Effects...
  - Desired set pressure = 10 barg
    - Superimposed variable BP = 0.5 to 2.0 barg
    - Cold Set Pressure = ???
    - The valve will open between 10.5 to 12.0 barg
  - Safety valve shall not open at a pressure higher than the MAP or PS (≈ design pressure)
    - If MAP < Cold Set + BP...
      - Conventional valve cannot be used, even if superimposed variable BP < 10% set
Balanced Bellows Safety Valve

- The Balanced Bellows
  - isolates top side of disc for Back-P
  - isolates spring and guide from outlet environment

- Typically, this type of valve can be used:
  - Any backpressure up to \( \approx 50\% \) of set
    - \( \approx \) absolute value of BP
    - \( \approx \) Reduced capacity
    - Check with manufacturer
Pilot Operated Safety Valves

- Main valve piston inherently balanced against backpressure
  - Theoretically no limit on backpressure
Back-Flow Preventer

- If BP > PS, back-flow may occur
  - Flare system:
    - start-up of installation
    - valves with different sets
  - vacuum in process
If BP > PS
back-flow may occur

- Flare system:
  - start-up of installation
  - valves with different sets
- vacuum in process
Back-Flow Preventer (POSV)

Backflow Preventer

$P_2 > P_1$