SAFETY DEVICE SIZING

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Structure of the article:

1. Cryogenic safety in operation (rules)

2. Accidental heat loads
   2.1 - System to be protected
   2.2 - Accidental situations and heat load

3. Method for sizing any safety relief device

English version will be available soon

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2.1 - SYSTEM TO BE PROTECTED

Safety relief devices

Examples of configurations

Vacuum vessel
Reservoir
Circuit
Examples of accidental situations (=> Overpressurisation):

Single failure: only one initiator event

- Air inlet => loss of vaccum
- Leak of cryogenic fluid: loss of vaccum
- Electric heater: Maximum power
- Quench of a supraconductive coil
- Immersed heat exchanger: (sudden Inlet of hot fluid)

The most probable and severe event has to be considered for sizing the safety relief device.
2.2 - HEAT LOAD IN CASE OF AIR LOSS OF VACUUM

- Bibliographic study of experimental heat fluxes for the main cryogenic fluids (He, H2, Ne, N2, O2, Ar) at $P_{atm}$
- Physical analysis of the experimental results

Heat flux data as function of number of layers (MLI) are given in the article...

- $\Phi$ Heat flux inlet on the system
- $S$ Cold surface exchange
- $\dot{Q}$ Heat power

\[ \dot{Q} = \Phi \cdot S \]
3 - METHOD FOR SIZING THE SAFETY DEVICE
Reservoirs, circuits, and vacuum chamber

Input data: Fluid, heat load \( \dot{Q} \), initial conditions \((P_i, \rho_i, T_i, N_i)\), discharge pressure \((P_0)\), geometry of the system

3 steps.....

Step 1: Determination of the discharged mass flow rate \( \dot{m}_0 \)

Calculate a mass flow rate that leads to a maximum section A. This section have to limit the pressure at \( P_0 \) during all the discharge transient

\[
\dot{m}_0 = \frac{\dot{Q}}{v \left( \frac{\partial h}{\partial v} \right)_{P_0}}
\]

\[
h' = v \left( \frac{\partial h}{\partial v} \right)_{P_0}
\]

\( h' \) is expressed depending on the thermodynamic state conditions of the system: sub-cooled liquid, two phase liquid-vapor, superheated vapor and supercritic fluid
CASE 1: SUPERCritical DISCHARGE (P_0 > P_C)

Section for an ideal safety device for a discharge at constant pressure 4 bar

\[ h' = v \left( \frac{\partial h}{\partial v} \right)_{P_0, T} \]

Standards NF-EN 13648-3

\[ T'_0 \text{ such as } \frac{\sqrt{v}}{v \left( \frac{\partial h}{\partial v} \right)_{P_0}} \max \]

The section A presents a maximum for \( v_0 = v(P_0, T'_0) \)

In the article’s CEA

\[ T_{vent} = T(v_i, P_0) \]

\[ T = \max(T_{vent}, T'_0) \]

\[ h' = v \left( \frac{\partial h}{\partial v} \right)_{P_0, T} \]
CASE 2: SUBCRITICAL DISCHARGE (P₀ < P_C) EX HELIUM

Section for an ideal safety device for a discharge at constant pressure 2 bar

\[ \dot{m}_0 = \frac{\dot{Q}}{v_{lsat0}} \left( \frac{v_{vsat0} - v_{lsat0}}{h_{lv0}} \right) \]

\[ \dot{m}_0 = \frac{\dot{Q}}{v_{vsat0}} \left( \frac{v_{vsat0} - v_{lsat0}}{h_{lv0}} \right) \]
Step 2: Calculation of the thermodynamic conditions, mass enthalpy $h_1$ and the pressures $P_1$ and $P_2$

- Pressure drop calculation to determine $\Delta P_1$ and $\Delta P_2$
- Energy balance to determine mass enthalpy $h_1$

Long discharge line $\dot{m}_0 \neq \dot{m}_1$

Expansion and change state due to $\dot{Q}_{\text{disch e_line}}$

See the article for more details.....

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Step 3: Calculation of the minimum section $A$ of the safety relief device

\[
A = \frac{\dot{m}}{G \times K_d}
\]

- $\dot{m}$: Mass flow rate to discharge ($\dot{m}_0$ or $\dot{m}_1$)
- $G$: Mass flux
- $K_d$: Discharge coefficient, depends on the geometry of the safety relief device and thermodynamic state of the fluid at upstream

G model: Isentropic expansion of flow in a short nozzle

\[
G = \rho_{\text{throat}} \times \sqrt{2 \times (h_1 - h_{\text{throat}})}
\]

Generic model (API 520):
- Valid for all thermodynamic states of the fluid upstream of the safety device
- Takes into account the possible phase change of the fluid during the expansion (evaporation / condensation)
• Software was developed several years ago at SBT using a first method

• This software has been updated to the content of the presented article

See presentation / talk of Jean-Marc Poncet
• Norme NF EN 13648-3, Récipients cryogéniques, Dispositifs de protection contre les surpressions, partie 3 : Détermination du débit à évacuer – Capacité et dimensionnement, décembre 2002

• W. Lehmann (KFK, TIP), Sicherheitstechnische Aspekte bei Auslegung und Betrieb von Lhe-badegekühlten, Supraleiter-Magnetkryostaten.


• E.G. Brentari, R.V. Smith, Nucleate and film pool boiling design for 02, N2, H2 and He, Advances in Cryogenic Engineering, 325-341, 1965.


Thank you for your attention
EXTRA SLIDES
SUBCRITICAL DISCHARGE (P0 < PC) (EXAMPLE FOR HELIUM)

Section for an ideal safety device for a discharge at constant pressure 2 bar.

Diagramme T-v He

Section par unité de puissance (m²/W)

A/Q calculé à P = P₀ et vₛ = v_sat0

A/Q calculé à P = P₀ et T = T_échappement

Liquide

Diphasique

Vapeur

V_i < v_sat0

V_i < v < v_sat0

V_i > v_sat0

Courbe de saturation

Isobare 1 bar

Isobare 2 bar

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DISCHARGE MAS FLOW AT CONSTANT PRESSURE $P_0$

EXPRESSION OF THE FUNCTION $H’$ IN TWO PHASES STATE

$$x = \frac{v - v_{vsat0}}{v_{vsat0} - v_{sat0}}$$

$$h = x \cdot h_{vsat0} + (1 - x) \cdot h_{lsat0}$$

$$\nu \left( \frac{\partial h}{\partial v} \right)_{P_0} = \nu \left( \frac{h_{lv0}}{v_{vsat0} - v_{lsat0}} \right)$$

$h_{lv0}$ : Latent heat at $P_0$

$v_{lsat0}$

$v_{vsat0}$

Specific volume of the vapour and the liquid at saturation and pressure $P_0$

but that must be taken to $\nu$ to calculate the flow $\dot{m}_0$
Identify the weak point of the cryogenic circuit that might become the source of the leak into the vacuum vessel and define the «breach» area:

\[ A_{\text{breach}} \]

(compensation below, connection, weld, burst disc…)

Non accumulation of cryogenic fluid in the vacuum vessel:

\[ \dot{m} = \dot{m}_{\text{breach}} \]

\[ \dot{m}_{\text{breach}} = A_{\text{breach}} \cdot G(P_{0\text{res}}, h_{0\text{res}}) \]

Example: Leakage through a burst disc of the tank