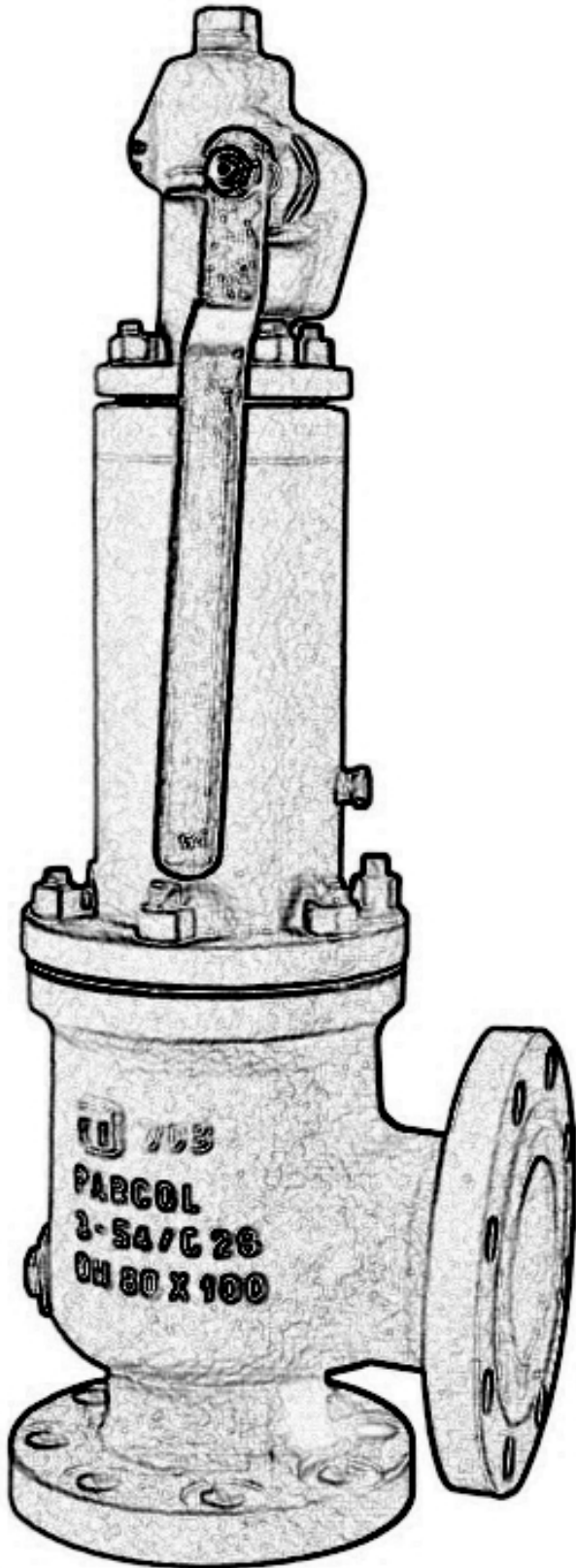


PARCOL



PRESSURE SAFETY RELIEF VALVES

TECHNICAL BULLETIN 3-I

0. FOREWORD

This technical bulletin is dedicated to those pressure relieving devices which fall within the definition of direct-loaded safety valves, produced by PARCOL since the beginning of the Seventies. The information contained in this document derive from PARCOL experience and internal instructions and are basically in accordance with the international standards listed in the following paragraph.

1. NORMATIVE REFERENCE

- API STANDARD 520 – Part I (2008), Sizing, Selection and Installation of Pressure-relieving Devices in Refineries – Sizing and selection
- API RECOMMENDED PRACTICE 520 – Part II (2003), Sizing, Selection and Installation of Pressure-relieving Devices in Refineries – Installation
- API STANDARD 526 (2009), Flanged Steel Pressure-relief Valves
- API STANDARD 527 (1991), Seat tightness of Pressure-relief Valves
- ISO 4126-1 (2004), Safety devices for protection against excessive pressure – Safety valves
- ISO 4126-7 (2004), Safety devices for protection against excessive pressure – Common data
- ISO 4126-9 (2008), Safety devices for protection against excessive pressure – Application and installation of safety devices excluding stand-alone bursting disc safety devices
- ISO-WD 4126-11 (2011), Safety devices for protection against excessive pressure – Performance testing



2. TERMS AND DEFINITIONS

Direct loaded safety valve

Safety valve in which the loading due to the fluid pressure underneath the valve disc is opposed only by a direct mechanical loading device such as a weight, lever and weight, or a spring.

Safety valve

Automatic pressure-relieving device actuated by the static pressure upstream of the valve and characterized by a rapid full opening or pop action.

It is normally used for gas or vapour service.

Relief valve

Automatic pressure-relieving device actuated by the static pressure upstream of the valve.

The valve opens in proportion to the increase in pressure over the opening pressure. It is primarily used for liquid service.

Safety-relief valve

Automatic pressure relieving device actuated by the static pressure upstream the valve.

It is suitable for use as either a safety or relief valve, depending on the application.

Max allowable working pressure (MAWP)

Maximum allowable working pressure for operation, in accordance to manufacturing codes and service conditions adopted as the basis for design.

Accumulation

Pressure increase over the MAWP value, expressed as percentage of the MAWP pressure, allowed in the pressurized system. Maximum allowable accumulations are established by applicable codes for operating and fire contingencies.

Set pressure (pset)

Predetermined pressure at which a safety valve under operating conditions commences to open. It is expressed in gauge units.

Three different ways may be used to detect the set pressure depending on the assigned definition:

- start of opening, which may be checked measuring the lift or hearing/seeing a continuous outflow;
- opening pressure, easily recognizable by the sudden movement of the disc (applicable only to compressible fluids);
- start-to-leak pressure, may be easily detected as soon as the first bubble or drop comes out (applicable only to valves having a perfect seal, e.g. with resilient seats).

Cold-differential test pressure

Pressure at which the valve is adjusted to open on the test bench, including the corrections for service conditions of back pressure, temperature, or both.

Overpressure (ovp)

Pressure increase over the set pressure, at which the safety valve attains the lift specified by the manufacturer, usually expressed as a percentage of the set pressure.
It is the overpressure used to certify the safety valve.

Relieving pressure (p1)

Pressure used for the sizing of a safety valve which is greater than or equal to the set pressure plus overpressure.

Lift

Actual travel of the valve disc away from the closed position.

Coefficient of discharge

Value of actual flowing capacity (from tests, by Manufacturer) divided by the theoretical flowing capacity (from calculation).

Blowdown (bd)

Difference between the set pressure and the reseating pressure, usually expressed as percentage of the set pressure.

Back pressure (pb)

Pressure on the discharge side of safety-relief valve, due to the pressure existing in the downstream system.

It is the sum of the built-up and of the superimposed back pressure.

It is expressed as:

- percentage of relieving pressure, calculated in absolute units for compressible fluids and in gauge units for incompressible fluids, according to ISO 4126;
- percentage of set pressure, calculated in gauge units, according to API.

Built-up back pressure

Pressure existing at the outlet of a safety valve caused by flow through the valve and the discharge system.

Superimposed back pressure

Pressure existing at the outlet of a safety valve at the time when the device is required to operate. It may be constant or variable.

Flow area

Minimum cross-sectional flow area between inlet and seat used to calculate the theoretical flow capacity.



3. DESCRIPTION AND OPERATING CRITERIA

Safety-relief valves may be considered as stop valves that close using a steady force insisting directly on the disc, thus no external actuator is needed.

When fitted in a pressurized system, they remain normally closed and open only if the force generated by the pressure is higher than the corresponding thrust insisting on the disc.

Safety valves are conceived to keep the pressure of the system, where they are fitted, under a stated value by discharging as much fluid as necessary for this purpose.

The force on the disc may be imposed through: a weight, a weight and a lever, a spring.

Weight loaded valves have a lift higher (and thus a higher flow) than spring loaded valves, being all other conditions unchanged, because the latter reacts proportionally to the lift while the former has a constant opposite force.

On the other hand, weight loaded valves have some disadvantages due to the inertial effect of the moving parts, which limits their use to light duties with low set pressure.

Direct spring loaded safety-relief valves may be distinguished into two main types:

- conventional valves,
- balanced valves.

Conventional non-balanced valves

Conventional non-balanced valves are applicable when no back pressure exists on the discharge side or when the back pressure does not alter the set pressure and the performance of the valve beyond known limits.

In practice they may be used without problems in case of atmospheric discharge.

They may have an open spring bonnet (i.e. vented) or a closed one, connected to the valve discharge. The closed type is allowable also for service on liquids or anyway when the fluid must not be spread outside

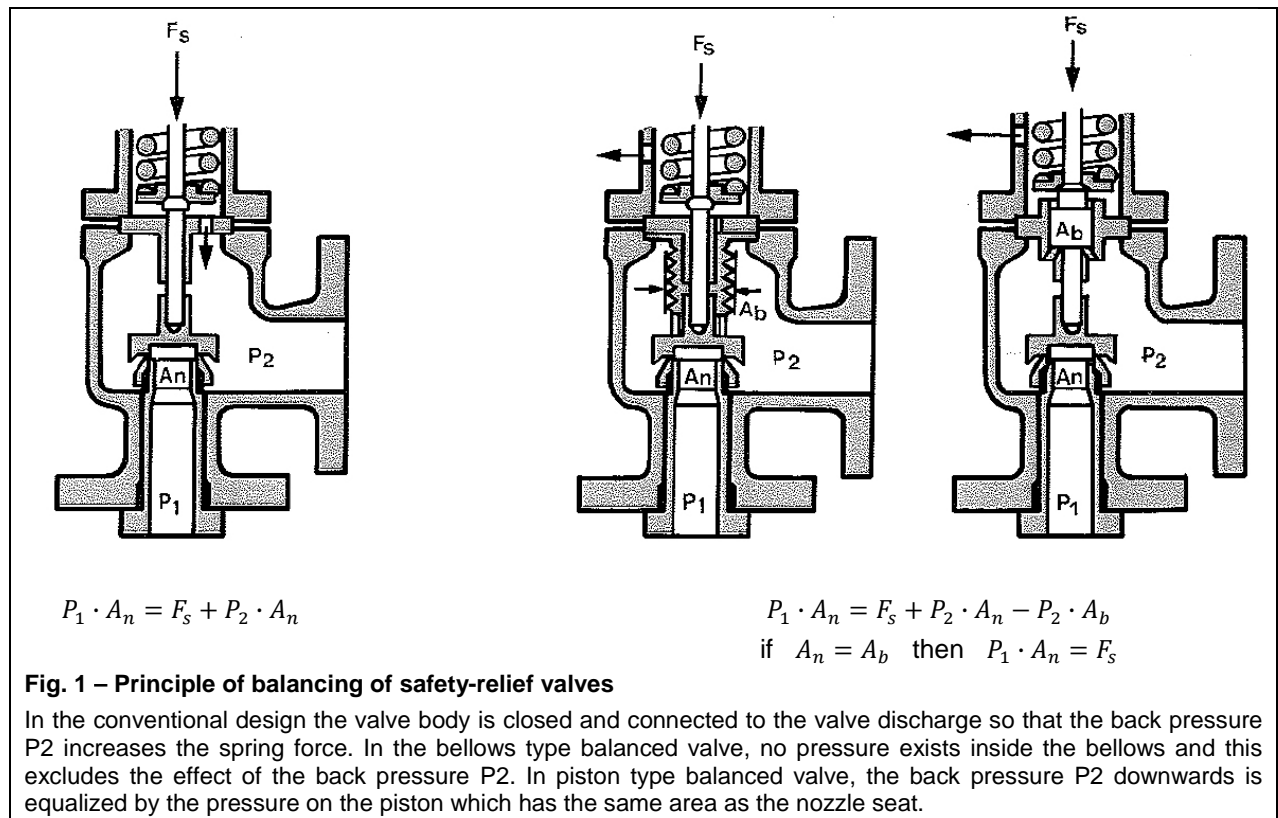
On **open bonnet** types, the influence of back pressure is negligible because they normally have a free air discharge.

In case of conveyed discharge, the possible back pressure may increase or decrease the set pressure depending on the valve design.

This kind of valve is usually fit on compressed air lines, where external leakages are acceptable, or far service on boiler or steam lines, where it is necessary to protect the spring from excessive heating

Balanced valves

The valve disc balancing is necessary when a variable or unpredictable back pressure exists, as for instance in petrochemical plants where all process fluid discharges must be conveyed for safety or environmental reasons.



In conventional valves, if the spring bonnet is vented to the discharge, the back pressure acts with the spring pressure on the whole surface of the disc retainer so as to increase the opening pressure (over the set pressure).

Balanced valves are designed in such a way to exclude the unbalanced area from the effect of the back pressure and vent it to atmosphere (see fig. 1). This is normally achieved by fitting a metallic **bellows** between disc retainer and valve body.

The bellows area is fairly equal to the nozzle seat area.

The bellows length is sized to allow the valve lift without being compressed too much.

Its assembling to the disc retainer is done in several manners taking into account that a good seal must always be performed towards the valve bonnet.

The upper part of the bellows has the shape of a disc which is blocked between spring bonnet and valve body and is nearly adherent to the supporting guide.

In other models the balance of the disc retainer is performed by a **piston** solidly connected to the stem and having the same diameter of the nozzle seat.

The balancing bellows allows also for the isolation of the spring from the process fluid. Sometimes this model is required for corrosive fluids for which there is no compatibility with the material of the spring.

The piston model does not allow perfect isolation because use of seals on moving parts of the valve would increase friction. On the other hand, the piston is much more reliable than the bellows, being the bellows subject to rupture under heavy duties (i.e. with steam at high temperature and pressure or due to wrong valve installation on piping overstressed by vibrations).

For the above reasons, PARCOL safety valves can be supplied with bellows in combination with piston for maximum reliability. Combination that PARCOL strongly recommends on heavy duty applications.

Relief valve

A relief valve opens in proportion to the increase in pressure over the opening pressure because the area where the pressure insists does not vary significantly with the lift.

Safety valves

A safety valve shows a quick opening of the disc achieved through particular devices which increase the area of pressure on the disc with the lift.

This effect, together with the reaction of the fluid, produces a sudden lift of the disc which may

reach a high value compared with the diameter of the seat (a ratio lift/nozzle higher than 0,3).

The most commonly used means to achieve this kind of operation (pop action) are an enlargement of the disc and a screwed ring fitted on the nozzle (see fig. 2) whose position is settable so as to create a restriction to the flow.

If the fluid is compressible, a pressure is generated in the huddling chamber located between the wing of disc retainer and the setting ring. This pressure causes a quick unbalance of the disc that increases the lift and therefore the flow of the fluid.

As soon as the pressure of the fluid reaches the set value, the disc begins to open.

At this point the pressure acts also on the outer side of disc wing. The lifting force increases quickly and causes a nearly instantaneous opening of the valve.

The position of the setting ring determines the pressure gradient on the disc wing during the initial lift.

If the ring is lifted against the disc then the effect of the secondary orifice is amplified: the opening overpressure decreases and the reclosing gap becomes greater.

The contrary happens if the ring is lowered.

The geometry of the disc retainer affects its dynamic reaction owing to the deviation of the flow and has a great influence on the lift when the discharged flow is considerable.

If the outflow from the disc is downwards the dynamic effect is maximum and its contribution to the lift is significant.

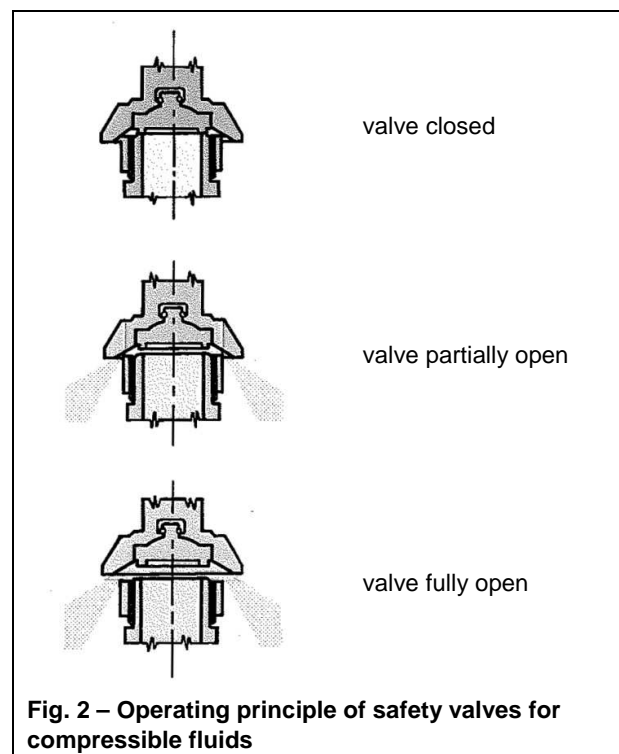


Fig. 2 – Operating principle of safety valves for compressible fluids

4. VALVE MAIN COMPONENTS AND CHARACTERISTICS

Body

It is generally angle shaped with threaded, welding ends or flanged connections. The discharge diameter is usually larger than the inlet diameter in order to improve the coefficient of discharge and to reduce the built-up back pressure.

The dimensions of the body centre-to-face are standardized by API 526 which, due to its origin, is not always complied with by the European manufacturers.

Bodies generally have different ratings between inlet and discharge.

In fact back pressure is always lower than inlet pressure, thus it would be costly and useless to adopt a single rating as done on conventional control valves.

As a matter of fact the whole valve is designed according to the P/T discharge side values except for the inlet flange, nozzle and disc.

All bodies are provided with drain plug which is useful in case of conveyed discharge when the downstream pipe is not duly drained.

Spring bonnet

It is fixed to the body through a flange (or a thread on smaller executions) and tightens the guide of the disc retainer.

In case of safety valves it may be made out of an open structure of two columns. Sometimes the closed bonnet of safety-relief valves is used with windows on the outer surface.

In the upper part of the bonnet the spring setting screw is fitted and is accessible only after having removed the cap.

A lead seal is performed between bonnet and cap when required by Official Parties in order to avoid an undue access to the setting screw.

The bonnet of safety-relief valves is vented to discharge side through openings in the guide.

Some models even have a connecting pipe between spring bonnet and discharge acting as an ejector to improve the depressurization in the bonnet and to improve the valve opening.

Nozzle

It is usually internally shaped according to a Venturi or equivalent profile that allows high coefficient of discharge.

The nozzle covers the entirety of the valve inlet duct and ends with a rib clamped during the mounting between body and pipe (or vessel).

On cheaper models, the nozzle has reduced dimensions (semi-nozzle) and is mounted inside the body quite like the seat of globe valves.

Normally this solution does not allow for high coefficients of discharge and may cause problems when operating at high temperatures (leakage under the nozzle, loosening).

The connection between nozzle and body is usually threaded. Every manufacturer adopts different solutions about particular coupling and centring positions of the two pieces.

The general rule is that the nozzle should not be rigidly fixed to the body so that possible stresses from the discharge pipe do not distort the body.

The top side of the nozzle has a flat ring where the disc retainer lays.

This sealing surface must be clean, smooth and have a little width in order to limit the blowdown and to allow a good repeatability of the set pressure.

The internal diameters of the nozzle (orifices) have been standardized by API 526 with the purpose of making easier the choice and the design of the valves.

Disc

The closure member of PARCOL safety valve series 3-5400 is made out of two pieces: the disc and the disc retainer.

Other versions have the sealing disc solidly connected to the stem which also acts as a guide. Due to the two pieces design (see fig. 3), the sealing part is not affected by thermal distortions which easily affect the seal of one piece closure member.

The sealing disc, is in fact designed in such a way to avoid high thermal gradients when operating with high temperature fluids.

Spring

It withstands the pressure and the dynamic stresses of the fluid with the purpose of keeping the valve in closed position and to reclose it after discharge.

This device undergoes torsional stresses in elasto-plastic conditions and may be subject to rupture, mainly when operating under high temperatures.

The most common effect, caused by severe stresses, is the relaxation which decreases the height of the spring and therefore the force at the beginning of the lift.

This phenomenon is always present but is more significant at temperatures above 300 °C with closed spring bonnet.

In order to improve the resistance to the stresses and decrease the relaxation, the spring of safety valves are set with previous loading cycles just beyond the torsional elastic threshold.

This procedure is carried out at PARCOL facilities on every spring in cold conditions (cold setting); hot setting is carried out for important and heavy applications.

The rupture of the spring is luckily an event which happens seldom, being the number of operations very low if compared to the valve life.

Rupture may be caused by:

- defects of the material;
- fatigue at low number of cycles;
- corrosion;
- hydrogen embrittlement.

Material defects are critical for components subject to fatigue with high number of cycles.

Thus, in the case of safety valves, they are only to be considered as worsening of other causes.

Ruptures due to fatigue at low number of cycles may happen on hardened materials under heavy stresses and high temperatures (e.g. tungsten steel spring).

Ruptures are more frequently caused by:

- corrosion, which reduces the effective cross section of the spring;
- embrittlement of the material due to presence of hydrogen or hydrogen sulphide.

Therefore it is important to select a suitable surface protection and treatment.

Chemical protection or galvanizing are not always recommended because there is a risk of hydrogen etching.

If hydrogen sulphide or its compounds are present in the ambient, it is recommended to adopt closed bonnets and to manufacture the spring with suitably resistant materials.

Setting range

PARCOL safety valves are set on the test bench as per Client's requirements.

Their regular operation is guaranteed, without spring change, within a set pressure range not exceeding the following:

- $\pm 10\%$ of the set pressure for set pressures up to 17 bar;
- $\pm 5\%$ of the set pressure for set pressures higher than 17 bar.

Changes in set pressure shall anyway be evaluated case by case: always contact Parcol Technical Department for a proper analysis.

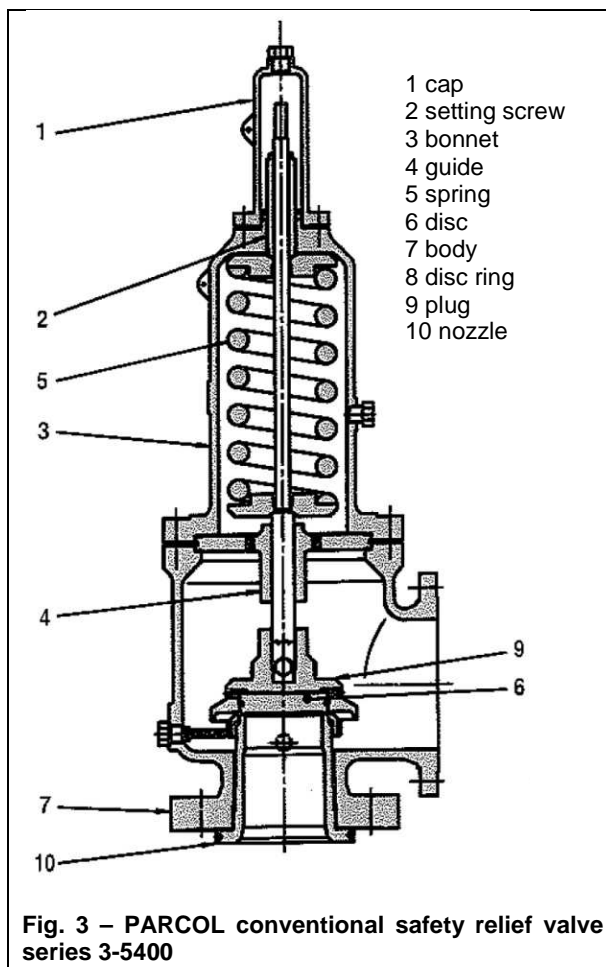
The minimum set pressure for conventional standard PARCOL valves is 0.5 bar while for balanced bellows valves this limit is approximately between 2.5 for the smallest orifices and 1 bar for the largest ones.

Lifting mechanism

If a periodical verification of the functionality is required (for instance by ASME Code Sect. VIII for operation with air, water or steam over 60 °C) the valve is fitted with a lifting lever suitable to cause the discharge of the valve when the pressure in the plant is at least 75% of the set pressure.

The device used on Parcol series 3-5400 is shown on fig. 4 and consists of an eccentric lever

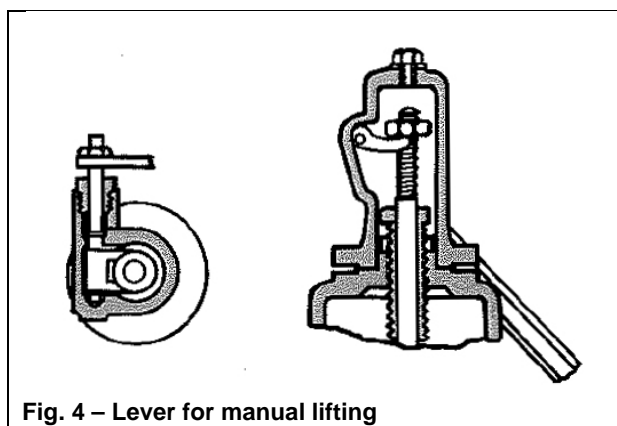
which automatically resets, after operation, to its initial position without hindering the opening of the valve.



The off position of the lifting lever shall be fixed and sealed against misoperation.

When no leakage of the discharge fluid is allowed, the movement of the lifting lever is transmitted to the internal side of the cap through a sealing stuffing box.

If the valve is located in not easily accessible sites, discharge tests may be carried out through chain or rope transmissions or by hydraulic, pneumatic or electric actuator.



5. INSTALLATION

Safety valves must be mounted vertically in such a position to be accessible for maintenance and setting operations (setting screw, blowdown ring nut, lifting lever).

In case of pressure vessel protection, it is recommended to install the valve on a nozzle directly fixed on the upper side of the vessel.

Different solutions are allowed only when the fluid inside the tank may be a source of vibrations which could affect the valve stability.

Almost all codes do not allow for stop valves between the equipment to be protected and safety valve.

When stop valve is tolerated, it must meet particular requirements: for instance, it shall not restrict the flow even if fully open.

Sometimes more than a safety valve is required whenever:

- a high flow rate would require the need of an enormous valve;
- alternate operation is necessary to avoid a plant shutdown;
- the maximum discharge flow rate is very high if compared with the normal operation of the plant.

In the first case it is convenient to install a Y branch having a flow section not less than the sum of the areas of the two orifices (see fig. 5).

If alternate operation is needed, being one valve as back-up to the other, it is necessary to use a three way distribution valve (also called "change-over valve") as shown in fig. 6.

In the latter case it is suitable to use parallel connected valves set at slightly different pressure so that only one valve works during normal operation of the plant.

Doing so, the usual inconvenients due to the use of only one oversized valve are avoided.

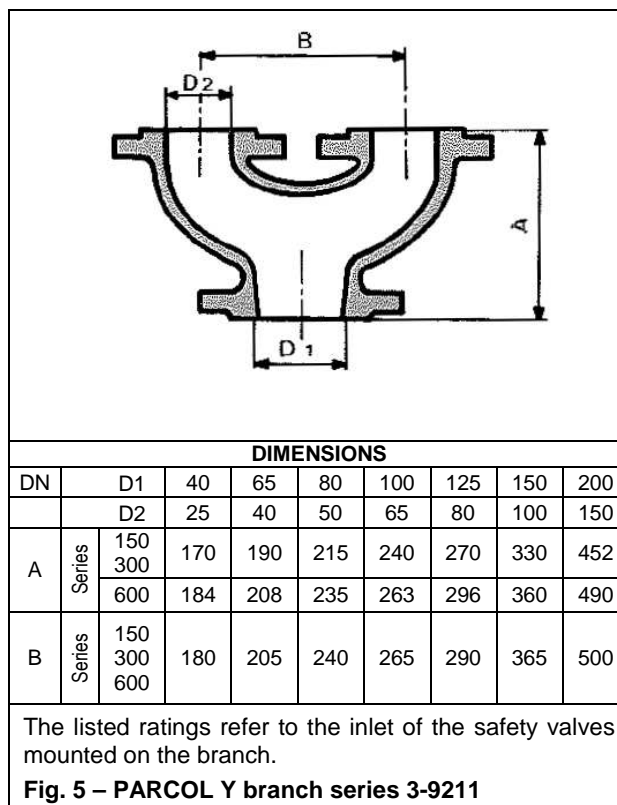
When the conveyed discharge has no adequate drain or when the position of the valve may cause internal accumulation of the condensate, then it is necessary to drain the body using its threaded connection.

Being the drain pipe a part of the discharge system, it must be subject to the same precautions used for the main discharge pipe. Particular care shall be paid to the design of piping upstream and downstream the safety valve.

API RP 520 Part II gives useful indications for carrying out such connections.

The upstream pipe shall have a flow section not lower than the minimum section of the valve and shall be as short as possible to keep the valve near the protected equipment.

Most common standards require a head loss between protected vessel and valve, at full discharge flow, not higher than 3% of the set pressure.



A higher head loss may in fact reach the blowdown value of the safety valve which causes its sudden closure and subsequent opening (chattering).

If the safety valve is installed on the pipe through a 90° branch, this one shall be correctly designed to avoid disturbances to the valve in closed position.

High fluid speed in the pipe may create resonances and subsequent pressure waves in the branch (till 6÷7 bar peak-to-peak) which modify the equilibrium of the closure member.

The results may be: unexpected openings, chattering, fluttering, fretting corrosion and leakages through the seal.

In order to avoid these inconvenient, the configuration of the connection must fall within the limits shown on fig. 7 taking into account the rounding of the branch entrance.

The design of the upstream pipe shall also consider the dynamic loads generated by the discharged fluid.

Fig. 8 shows the sizing formulas to this purpose.

In case of toxic gases (needing a safe seal) or of particular operating conditions which can affect the performance of the safety valve (if it is in contact with the fluid), the use of rupture discs is

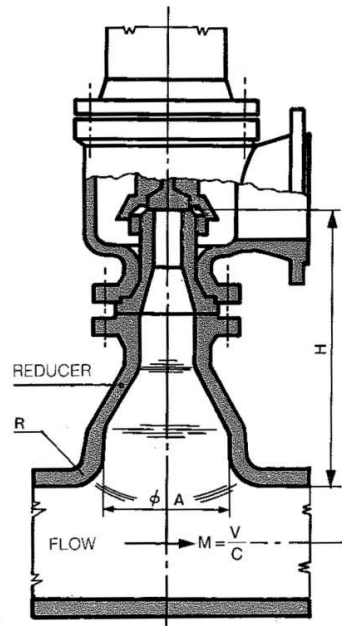


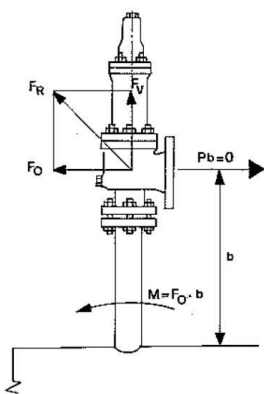
Fig. 7 – Proper mounting of safety valves on pipes

To avoid disturbances to the valve in closed position, the ratio AH shall be higher than 2.4 M (being M the Mach number of the fluid in the main pipe)

Fig. 8 – Discharge reaction forces of a pressure relief valve on gas service

Reaction forces include the effects of momentum and static pressure respectively on inlet valve axis (F_v and F'_v) and on outlet valve axis (F_o and F'_o). Terms related to static pressure are in square parenthesis.

Reaction forces are calculated assuming steady-state critical flow discharge conditions. In particular, the formula for F_o is according to API RP 520 Part II. For correct calculation of F_v it is necessary to know the back pressure p_b and the layout of venting pipe. For atmospheric vents consider $p_2 \approx 0$. Term F_v is anyway usually negligible compared to F_o . In case of impulsive-state discharge conditions, calculated values shall be doubled.



$$F_o = \frac{Q_{max}}{27.8} \sqrt{\frac{k}{k+1} \cdot \frac{T_1}{M}} + [10 \cdot p_2 \cdot A_2]$$

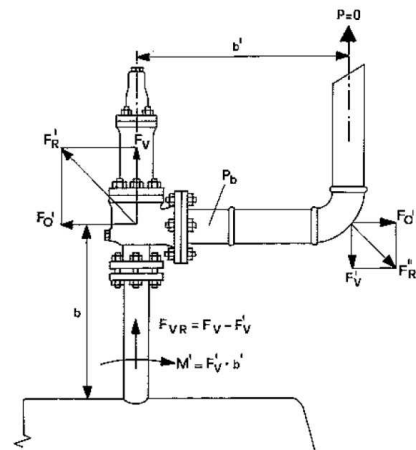
$$F_v = \frac{Q_{max} \cdot u_1}{3600} + [10 \cdot p_1 \cdot A_1]$$

$$F'_o = F_o + [10 \cdot p_b \cdot A_2]$$

$$F'_v \cong F_o$$

For practical use:

$$F_o = 0.1 \cdot Q_{max} \sqrt{\frac{p_1}{\rho_1}}$$



A_1 = area of inlet passage section [cm^2]

A_2 = area of outlet passage section [cm^2]

M = molar mass of the flowing fluid [kg/kmol]

p_1 = relieving pressure [barg]

p_2 = constant super-imposed back pressure [barg]

p_b = built-up back pressure [barg]

Q_{max} = maximum dischargeable flow rate [kg/h]

T_1 = inlet temperature of fluid [K]

ρ_1 = specific mass at inlet [kg/m^3]

u_1 = average fluid velocity at inlet connection [m/s]

k = specific heat ratio [-]

Note: reaction forces are expressed in Newton

strongly recommended.

A typical installation is shown on fig. 9.

If the fluid cannot be discharged into the atmosphere for safety reasons, then the outlet of the safety valve is connected to a downstream pipe leading to a collecting tank or, as often happens in petrochemical plants, to a collector leading to a torch.

The design of the pipe downstream may be critical for the choice and operation of the safety valve mainly because of the back pressure developed at the body outlet.

When the valve discharges into a collector whose pressure is unknown, a balanced valve shall be used.

An unknown back pressure may originate serious inconvenient, the worst of which is the loss of flow capacity due to insufficient valve opening or due to the change of the outflow from critical to subcritical.

The downstream pipe shall be installed in such a way to do not transmit heavy stresses to the valve body.

Sliding supports shall be provided and long straight pipes shall not be directly connected to the valve discharge.

For gases and vapours the downstream pipe shall be oriented upwards and be provided with drain holes.

For liquids it is recommended to have a discharge pipe downwards to avoid the flooding of the valve body.

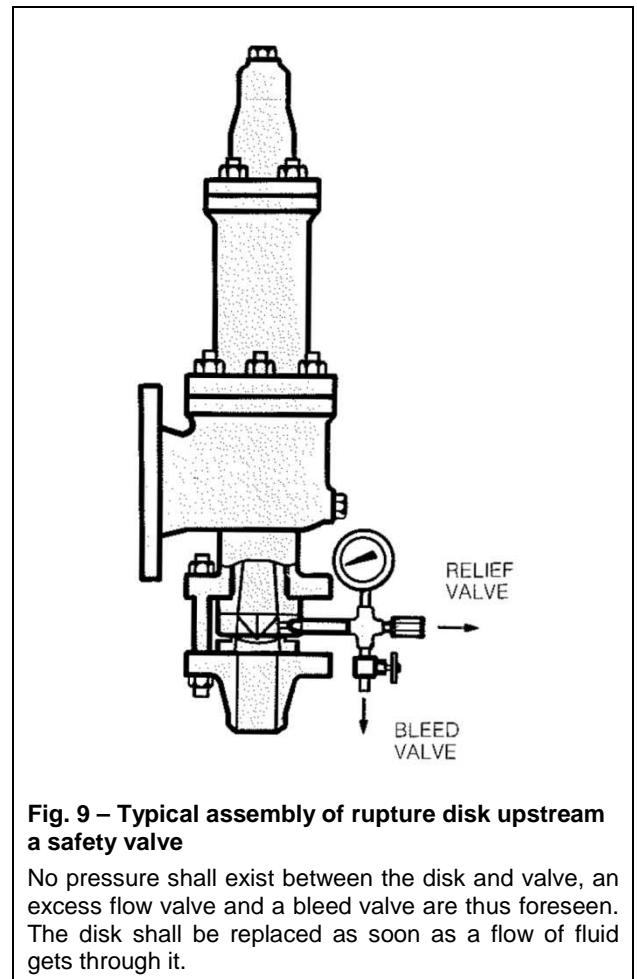


Fig. 9 – Typical assembly of rupture disk upstream a safety valve

No pressure shall exist between the disk and valve, an excess flow valve and a bleed valve are thus foreseen. The disk shall be replaced as soon as a flow of fluid gets through it.

6. SETTING TEST

The setting test of safety-relief valves may be performed with different procedures depending on:

- how the set pressure is defined (refer to paragraph «Terms and Definitions»);
- the kind of fluid;
- the available test equipment;
- the test location (bench or line).

The procedure usually followed by PARCOL for the setting test on the stand is to increase the upstream pressure till continuous flow is discharged; for gases this is brought to evidence by a well known noise or whistle while for liquids this is shown by an uninterrupted stream.

In the USA it is common practice for gases to take as set pressure the popping pressure, which is easily detectable and may coincide with the opening pressure if a proper setting of the blowdown ring is made.

The maximum deviation of the set pressure versus the required value is:

- ± 0.15 bar for set pressure lower than 5 bar;
- $\pm 3\%$ for set pressure higher than 5 bar.

The set pressure (differential pressure at cold condition) shall take into account the operating back pressure and temperature.

For non balanced valves with closed spring bonnet, the back pressure, if constant, is deducted from the set pressure (i.e. the spring is less compressed).

The effect of the operating temperature is taken into account increasing the setting as listed here below:

Operating temperature [°C]	Set pressure increase
up to 100	0
101 ÷ 250	2%
251 ÷ 500	3%
over 500	5%

Correction for temperature shall anyway be evaluated case by case, according to effective service conditions and Client's requests.

7. TIGHTNESS TEST

The tightness test is performed closing the valve discharge with a 6 x 8 mm flanged pipe, 90° bent and immersed for a depth of 13 mm (see fig. 10). The leakage is evaluated counting the bubbles outgoing the pipe and keeping the upstream air pressure at 90% of the set pressure. Valves with setting lower than 3.5 bar are tested with an upstream pressure 0.35 lower than the set pressure.

The time duration of the test shall be at least:

- 1 minute for valves with 2" DN and less;
- 2 minute for valves till 4" DN;
- 5 minute for valves with higher DN.

Acceptance criteria (as per API 527) are summarized on the diagrams of fig. 11.

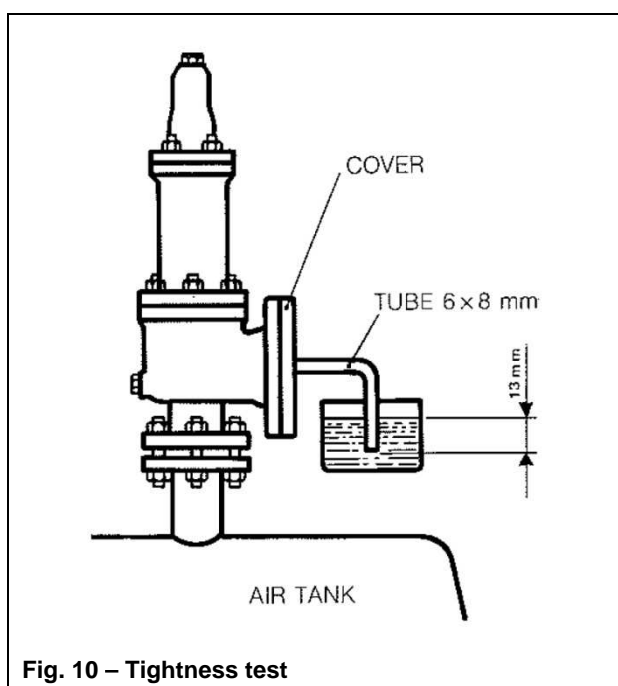


Fig. 10 – Tightness test

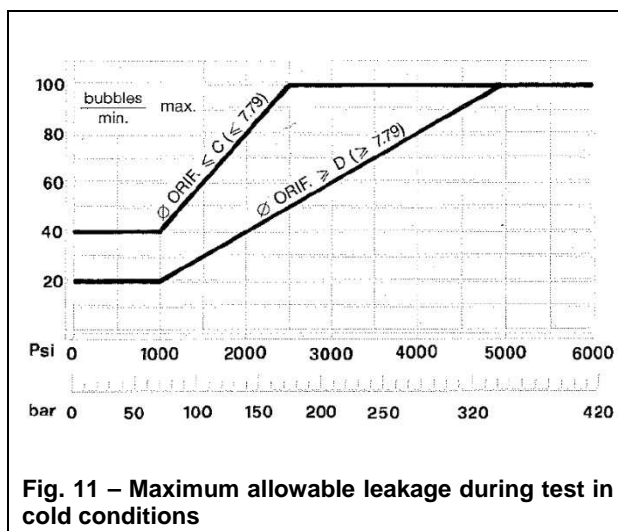


Fig. 11 – Maximum allowable leakage during test in cold conditions

8. NOISE LEVEL

The discharge noise of a safety valve may reach intensities dangerous to the hearing when operating with high pressure gas or vapours. Luckily, the number and duration of discharges is very low, therefore the acoustic problem is not considered critical and some standards allow for a noise level up to 135 db in proximity to the discharge.

If the position of the discharge is high, the noise spreading is spherical, which means a 6 db decrease for every doubling of the distance from the source, so that, if the distance increases from 1 to 30 m the noise level decreases by approximately 30 db.

To accept 135 db at 1 m means to accept 105 db at a distance of 30 m: though high, this noise level is tolerable for very short periods.

The solution of noise problems is anyway not easy because silencers are expensive and cause back pressures which may not be tolerated by valve and plant.

The only remedies are:

- to install the discharge as high as possible (so to have a better spreading) and as far as possible from personnel;
- acoustical insulation of valve and discharge pipe (if present) for at least 10÷15 m;
- a reasonable advantage may be reached by dividing the discharge (in case of large dimensions) into few ducts duly shaped and sized with regard to each other.

A simple way is to insert a drilled disc in the outlet duct which must be enlarged like a diffuser (see fig.12).

This solution leads, on the other hand, to back pressure problems and its reducing effect is not high (less than 15 db).

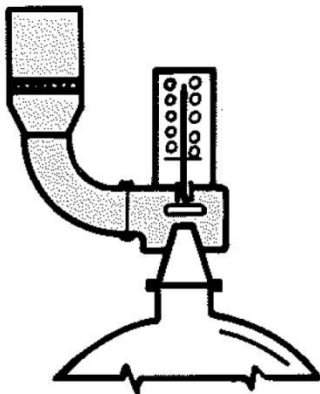


Fig. 12 – Drilled disc device mounted on the discharge of a safety valve to achieve noise reduction

No pressure shall exist between the disk and valve, an excess flow valve and a bleed valve are thus foreseen. The disk shall be replaced as soon as a flow of fluid gets through it.

Calculation of noise

The following formulas are valid to evaluate noise level from valve only when sonic conditions are reached at the outlet.

Noise level at 1 meter from valve is calculates as:

$$L_{p(A)_1} = 86 + 10 \log \left(\frac{Q_m \cdot k \cdot T_2}{M} \right)$$

where:

- $L_{p(A)}$ is the noise level [db(A)];
- Q_m is the mass flow rate [kg/h];
- k is the isentropic coefficient [-];
- T_2 is the discharge temperature;
- M is the molar mass [kg/kmol].

For distances higher than 1 meter and discharge fairly near to the soil, the noise level is:

$$L_{p(A)_low} = L_{p(A)_1} - 20 \log(L) + 3$$

where L is the distance in meters between measuring point and discharge point.

For distances higher than 1 meter and discharge high over the soil, the noise level is instead:

$$L_{p(A)_high} = L_{p(A)_1} - 20 \log(L)$$

9. VALVE SIZING

PARCOL pressure safety relief valves are usually sized as follows:

- according to ISO 4126-1 for gas, vapour, steam, liquid or alternate discharge of gas and liquid;
- according to API 520-1 Annex C for two-phase mixtures.

Alternative sizing can be performed, on request, according to other recognized international standards or according to Client's specifications.

Sizing for gas and vapour service

According to ISO 4126-1, the formula to be used is:

$$A_g = \frac{Q_m}{0.9 \cdot 100 \cdot p_1 C K_d K_b} \sqrt{\frac{T_1 Z}{M}}$$

where:

- A_g is the minimum required area [cm^2];
- Q_m is the mass flow rate [kg/h];
- p_1 is the relieving pressure [bar abs.];
- T_1 is the relieving temperature [K];
- Z is the compressibility factor [-];
- M is the molar mass [kg/kmol];
- C is function of the specific heat ratio k [-];
- K_d is the certified coefficient of discharge (from test, by Manufacturer) [-];
- K_b is the theoretical capacity correction factor for subcritical flow [-].

The subcritical flow occurs when the following inequality is verified:

$$\frac{p_b}{p_1} > \left(\frac{2}{k+1} \right)^{k/(k-1)}$$

where k is the specific heat ratio of the fluid.

In this case, K_b is calculated according to the following equation:

$$K_b = \sqrt{\frac{\frac{2k}{k-1} \left[\left(\frac{p_b}{p_1} \right)^{2/k} - \left(\frac{p_b}{p_1} \right)^{(k+1)/k} \right]}{k \left(\frac{2}{k+1} \right)^{(k+1)/(k-1)}}$$

In case of critical flow, K_b is equal to 1.

The coefficient C is calculated as follows:

$$C = 3.948 \sqrt{k \left(\frac{2}{k+1} \right)^{(k+1)/(k-1)}}$$

Example 1

Calculate the minimum flow area to discharge compressed air at the following conditions:

- $p_{set} = 8 \text{ barg}$;
- $T_1 = 50 \text{ }^\circ\text{C}$
- $Q_m = 10\,000 \text{ kg/h}$;
- $ovp = 10\%$;
- $p_b = 2.5 \text{ barg}$;

First of all, let us verify the flow type (critical or subcritical).

Being:

- $p_1 = p_{set} + ovp + 1 = 9.8 \text{ bar}$;

- $k = 1.4$;

the inequality is not verified.

$$\frac{3.5}{9.8} = 0.357 < \left(\frac{2}{2.4} \right)^{1.4/0.4} = 0.528$$

The flow is critical and K_b is equal to 1.

The coefficient C is equal to:

$$C = 3.948 \sqrt{1.4 \left(\frac{2}{2.4} \right)^{2.4/0.4}} = 2.703$$

Under the hypothesis to supply a valve having a certified coefficient K_d equal to 0.835 at 35.7% of back pressure (always refer to Manufacturer's for proprietary values), the minimum required area is:

$$A_g = \frac{10\,000}{0.9 \cdot 100 \cdot 9.8 \cdot 2.703 \cdot 0.835} \sqrt{\frac{323 \cdot 1}{28.964}} = 16.78 \text{ cm}^2$$



Fig. 13 – PARCOL safety relief valve during discharge test at “Fluid-dynamics of Turbomachines” Laboratories (LFM) at “Politecnico di Milano” University (air test bench)

Sizing for liquid service

According to ISO 4126-1, the formula to be used is:

$$A_l = \frac{Q_m}{0.9 \cdot 100 \cdot 1.61 \cdot K_d K_v} \sqrt{\frac{v_1}{p_1 - p_b}}$$

where:

- A_l is the minimum required area [cm^2];
- Q_m is the mass flow rate [kg/h];
- p_1 is the relieving pressure [bar abs.];
- v_1 is the specific volume at relieving conditions [m^3/kg];
- p_b is the back pressure [bar abs.];
- K_d is the certified coefficient of discharge (from test, by Manufacturer) [-];
- K_v is the viscosity correction factor [-].

The viscosity correction factor is function of Reynolds number, according to the following formula:

$$K_v = \left(0.9935 + \frac{2.878}{Re_v^{0.5}} + \frac{342.75}{Re_v^{1.5}} \right)^{-1.0}$$

Reynolds number is calculated as follows:

$$Re_v = \frac{31.3 \cdot Q_m}{\rho_0 \mu \sqrt{A_l}}$$

where:

- ρ_0 is the specific mass of water at 20 °C, equal to 1 kg/dm^3 ;
- μ is the dynamic viscosity [cp].

Being the Reynolds number function of A_l , an iterative calculation is required.

Example 2

Calculate the minimum flow area to discharge pressurized water at the following conditions:

- $p_{set} = 30$ barg;
- $T_1 = 20$ °C;
- $Q_m = 85\,000$ kg/h;
- $ovp = 10\%$;
- $p_b = \text{atmospheric}$.

The relieving pressure is:

- $p_1 = p_{set} + ovp + 1 = 34$ bar;

From water data:

- the specific volume is 0.0010 m^3/kg ;
- water viscosity is negligible, then K_v is equal to 1 and no iterative calculation is required.

Under the hypothesis to supply a valve having a certified coefficient K_d equal to 0.740 without back pressure (in percentage terms, the back pressure is null), the minimum required area is:

$$A_l = \frac{85\,000}{0.9 \cdot 100 \cdot 1.61 \cdot 0.740} \sqrt{\frac{0.0010}{34 - 1}} = 4.36 \text{ cm}^2$$

Always remember to refer to Manufacturer's for proprietary certified coefficient of discharge.



Fig. 14 – PARCOL safety relief valve during discharge test at “Fluid-dynamics of Turbo-machines” Laboratories (LFM) at “Politecnico di Milano” University (water test bench)



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