# British Standard

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# Safety valves

## Part 1. Specification for safety valves for steam and hot water

Soupapes de sûreté
Partie 1. Soupapes de sûreté pour vapeur et eau chaude. Spécification

Sicherheitsventile
Teil 1. Dampt- und Warmwassersicherheitsventile



British Standards

## Contents

## Foreword

The preparation of this British Standard has been undertaken under the direction of the Pressure Vessel Standards Committee to incorporate such requirements as are necessitated by technical developments and to comply with the requirements of ISO 4126 'Safety valves, general requirements', published by the International Organization for Standardization.

The opportunity has been taken to bring together in one standard the requirements for safety valves. The standard will be published in three Parts as follows:

- Part 1. Specification for safety valves for steam and hot water
- Part 2. Specification for safety valves for compressed air and inert gases (in course of preparation)
- Part 3. Specification for safety valves for process fluids (in course of preparation)

Part 1 requires that safety valve designs shall be type tested for their operational and flow characteristics to the satisfaction of an independent authority. In order to give manufacturers a period of grace in which to align their products with this standard, BS 759 : Part 2 has been created by amendments to the 1975 edition of BS 759 which will be retained as an obsolescent standard until it is withdrawn in December 1987.

To assist manufacturers and inspecting authorities, a list of testing establishments, together with details of facilities available, has been compiled and is available on request from the Enquiry Section (London), British Standards Institution.

The hydraulic pressure testing requirements for components to this standard are in many cases equal to or greater than those for the boiler to which they may be fitted, but in any case it can be taken that any safety valve body will be capable of sustaining a hydraulic test pressure equal to 1.5 times the design pressure of the valve as specified to the valve supplier by the purchaser. For this purpose a safety valve is gagged or the seat blanked off as appropriate during the test.

Appendix A gives the derivation of the superheat correction factors listed in table 5 and which are used to calculate the certified discharge capacity of a safety valve discharging superheated steam.

Appendix B provides guidance on the mounting of safety valves and includes recommendations for discharge piping and drainage. The advice given in this appendix is intended to eliminate the detrimental effects on the performance of safety valves which may arise from influences associated with incorrect mounting.

It is recognized that clauses (reproduced in appendix C) regarding inspection facilities and testing facilities which have traditionally been incorporated into safety valve standards are a contractual matter. Nevertheless their importance is such that the purchaser in agreeing a contract should not overlook them.

This Part of this standard deals with the materials, construction, and testing of safety valves and associated capacity calculations, but is not intended to cover all details of their installation, for which additional reference should be made to the appropriate British Standard.

NOTE 1. In order to ensure the correct functioning of boiler safety valves, it is essential that suitable equipment be provided to enable the proper condition of the feedwater to the boiler and the water in the boiler to be maintained.

NOTE 2. Attention is directed to the recommendations contained in 'Guidance Note PM5' entitled 'Automatically controlled steam and hot water boilers' issued by the Health and Safety Executive.

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

British Standard

# Safety valves

Part 1. Specification for safety valves for steam and hot water

## Section one. General

### 1. Scope

This Part of this British Standard specifies requirements for safety valves for steam and hot water where the set pressure is greater than 1 bar gauge.

It includes requirements for safety valves for boilers, boiler installations and associated pipework systems where the steam pressure exceeds 1 bar gauge or, in the case of hot water boilers, where the rating is 44 kW and above, as well as for boilers pressurized by steam for use in hot water systems which are classified as steam boilers.

Requirements for testing safety valves for determination of their operating and flow characteristics are given.

Recommendations on safety valve mounting, discharge piping and drainage are given in appendix B.

This standard does not cover safety valves for boilers used in open vented hot water systems working at temperatures not exceeding 100 °C, nor safety valves for storage water heaters of the unvented type which normally operate at temperatures not exceeding 82 °C and at pressures not exceeding 10 bar*. For such boilers within the scope of BS 779 and BS 855 the requirements are incorporated in those standards.

NOTE. The titles of the publications referred to in this standard are listed on the inside back cover.

### 2. Definitions

For the purposes of this Part of BS 6759 the following definitions apply.

**2.1 safety valve.** A valve which automatically, without the assistance of any energy other than that of the fluid concerned, discharges a certified quantity of the fluid so as to prevent a predetermined safe pressure being exceeded, and which is designed to re-close and prevent the further flow of fluid after normal pressure conditions of service have been restored.

**2.1.1 direct loaded safety valve.** A safety valve in which the loading due to the fluid pressure underneath the valve disk is opposed only by direct mechanical loading such as a weight, a lever and weight, or a spring.

**2.1.2 assisted safety valve.** A direct loaded safety valve which, by means of a powered assistance mechanism, is lifted at a pressure below the unassisted set pressure and will, even in the event of failure of the assistance mechanism, comply with all the relevant requirements for safety valves given in this standard.

**2.1.3 supplementary loaded safety valve.** A safety valve which

(a) has, until the pressure at the inlet of the safety valve reaches set pressure, an additional force (supplementary load) to increase the sealing force, which may be provided by means of an extraneous power source which is reliably released when the pressure at the inlet of the safety valve reaches the set pressure, and

(b) attains its certified discharge capacity in the event of the supplementary loading not being released at an over-pressure not exceeding 115 % of the set pressure.

**2.1.4 pilot operated safety valve (indirect loaded safety valve).** A safety valve, the operation of which is initiated and controlled by the fluid discharged from a pilot valve which is itself a direct loaded safety valve.

**2.2 blowdown of a safety valve†.** The difference between the set pressure and the reseating pressure, normally stated as a percentage of set pressure, except for very low set pressure when the blowdown is then expressed in bar.

**2.3 boiler operating pressure.** In the case of fully-flooded hot water boilers, not externally pressurized, the maximum operating pressure in the hot water system, including any static head.

In the case of externally pressurized fully-flooded hot water boilers, the pressure at which the boiler operates.

**2.4 built-up back pressure.** The pressure existing at the outlet of the safety valve caused by flow through the valve and the discharge system.

**2.5 certified discharge capacity.** That portion of the measured capacity permitted to be used as a basis for the application of a safety valve.

NOTE. The certified discharge capacity is derived from either measured flow rate x derating factor or theoretical flow rate x coefficient of discharge x derating factor.

**2.6 cold differential test pressure.** The inlet static pressure at which a safety valve is set to commence to lift on the test stand. This test pressure includes corrections for service conditions of back pressure and/or temperature.

**2.7 commencement of lift.** Initial lift such as would cause the first indication of movement on a linear transducer or equivalent.

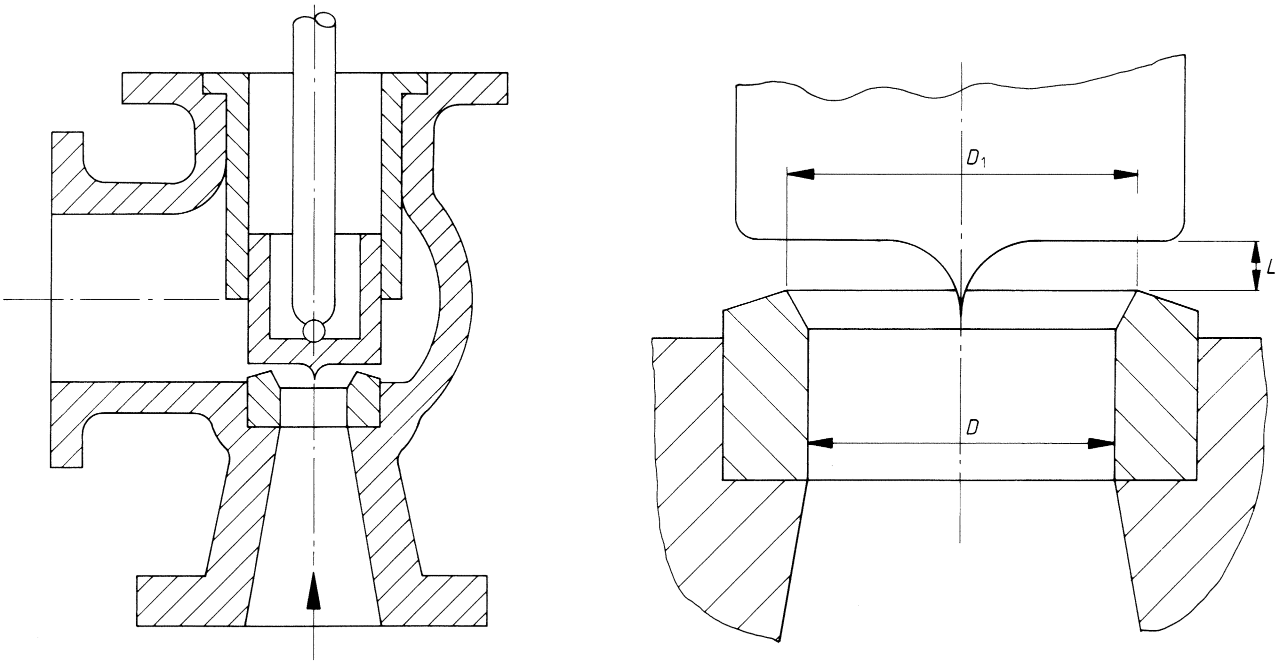
NOTE. Provision of such instrument facility only applies to valves under operating characteristics tests.

**2.8 design pressure.** The pressure used in calculating the thickness of a vessel or pipe system.

**2.9 discharge area of a safety valve.** The minimum cross-sectional area between inlet and seat, including the curtain

* 1 bar = $10^5$ N/m² = 100 kPa.

† The limits of blowdown are given in **19.1**.




NOTE. The discharge area is the lesser of the curtain area ($\pi D_1 L$) or the flow area ($\frac{\pi}{4} D^2$), see **2.9** and **2.12**.

**Figure 1. Illustration of area definitions**

area, which controls the flow of fluid through the safety valve when it is discharging its rated discharge capacity.

NOTE. See figure 1.

**2.10 double safety valve.** A safety valve with two body seats in one body.

**2.11 equivalent calculated capacity.** The calculated capacity of the safety valve for conditions of pressure, temperature or nature of the fluid which differ from those for which certified capacities are available.

**2.12 flow area.** The minimum cross-sectional flow area (but not the curtain area) between inlet and seat which is used to calculate the theoretical flow rate, with no deduction for any obstruction.

NOTE. See figure 1.

**2.13 flow diameter.** The diameter corresponding to the flow area.

**2.14 independent authority.** The competent independent authority which bears responsibility for all aspects of surveillance of tests, checking of calculations and certification of safety valve discharge capacities.

**2.15 inspecting authority.** The competent independent authority or association which verifies compliance with this standard.

**2.16 lift.** The travel of the disk away from the closed position.

**2.17 nominal size (DN).** A numerical designation of size which is common to all components in a piping system other than components designated by outside diameter or by thread size. It is a convenient round number for reference purposes and is only loosely related to manufacturing dimensions.

**2.18 overpressure of the safety valve.** A pressure increase over the set pressure of a safety valve, usually expressed as a percentage of set pressure.

**2.19 relieving pressure (flow rating pressure).** Set pressure plus overpressure.

**2.20 reseating pressure of a safety valve.** The value of inlet static pressure at which the disk re-establishes contact with the seat or at which lift becomes zero.

**2.21 set pressure.** The predetermined pressure at which a safety valve under operating conditions should commence to lift. It is the gauge pressure measured at the valve inlet at which the pressure forces tending to open the valve for the specified service conditions are in equilibrium with the forces retaining the valve disk on its seat.

**2.22 single safety valve.** A safety valve with one body seat only.

**2.23 theoretical flowing (discharge) capacity.** The calculated capacity expressed in gravimetric or volumetric units of a theoretically perfect nozzle having a cross-sectional flow area equal to the flow area of a safety valve.

## Section two. Material requirements and limitations

### 3. Pressure containing components

**3.1 Material specification.** The materials used in the manufacture of bodies and bonnets of safety valves shall comply with whichever of the following is appropriate bearing in mind that fittings of the less ductile materials are more likely to fail under shock conditions.

(a) Cast carbon steel to BS 1504-161, grade 480.

NOTE. This material has a maximum carbon content of 0.30 %. For valves with butt welded ends less than 35 mm thick and intended for welding into pipelines subject to the requirements of BS 2633, the carbon content should be 0.25 % maximum. Alternatively, the material may be specified as BS 1504-161, grade 430.

(b) Cast carbon ½ % molybdenum steel to BS 1504-245.

(c) Cast 1 ¼ % chromium ½ % molybdenum steel to BS 1504-621.

(d) Cast 2¼ % chromium 1 % molybdenum steel to BS 1504-622.

(e) Cast austenitic chromium nickel steel to BS 1504-347C17, or cast austenitic chromium nickel molybdenum steel to BS 1504-316C16.

(f) Forged carbon steel to BS 970 : Part 1, 070M20.

(g) Forged carbon steel to BS 1503 221-430.

(h) Forged carbon ½ % molybdenum steel to BS 1503 245-420.

(i) Forged 1 % chromium ½ % molybdenum steel to BS 1503 620-440.

(j) Forged 1¼ % chromium ½ % molybdenum steel to BS 1503 621-460.

(k) Forged 2¼ % chromium 1 % molybdenum steel to BS 1503 622-560.

(l) Forged chromium molybdenum vanadium steel to BS 1503 660-460.

(m) Forged austenitic chromium nickel steel to BS 1503 321S51-490 or BS 1503 347S51 or, forged austenitic chromium nickel molybdenum steel to BS 1503 316S51.

(n) Cast iron with minimum mechanical properties equal to those specified in BS 1452 grade 220.

(o) Cast copper alloy with minimum mechanical properties equal to those specified in BS 1400 for LG 2.

(p) Other material having properties at least equal to those of the material to which it is an intended alternative, subject to the limitations given in **3.2** and to agreement between the manufacturer and the purchaser, such agreement being approved by the inspecting authority.

**3.2 Pressure and/or temperature limitations**

**3.2.1** *Cast iron.* Cast iron shall not be used for the following:

(a) temperatures above 220 °C;

(b) pressures exceeding 13 bar gauge;

(c) valves exceeding 200 mm nominal bore which are connected directly to the boiler.

**3.2.2** *Cast copper alloy.* Cast copper alloy shall not be used for temperatures above 260 °C.

**3.2.3** *Steel*

**3.2.3.1** There are no pressure limitations on steel. Temperature limitations are given in **3.2.3.2** to **3.2.3.7** where the letters in parentheses refer to items listed in **3.1**.

**3.2.3.2** Cast carbon steel (a) and forged carbon steel (f) and (g) shall not be used at temperatures above 480 °C.

**3.2.3.3** Cast carbon molybdenum steel (b) and forged carbon molybdenum steel (h) shall not be used at temperatures above 540 °C.

**3.2.3.4** Cast chromium molybdenum steel (c) and forged chromium molybdenum steel (i) shall not be used at temperatures above 565 °C.

**3.2.3.5** Cast chromium molybdenum steel (d) and forged chromium molybdenum steel (j) and (k) shall not be used at temperatures above 580 °C.

**3.2.3.6** Forged chromium molybdenum vanadium steel (l) shall not be used at temperatures above 580 °C.

**3.2.3.7** Cast austenitic chromium nickel steel and cast austenitic chromium nickel molybdenum steel (e) and forged austenitic chromium nickel steel and forged austenitic chromium nickel molybdenum steel (m) shall not be used at temperatures above 700 °C.

NOTE. At temperatures above 680 °C it is generally accepted that the rate of oxidation or chemical attack begins to be important.

## 4. Body seat faces and valve disk faces

Body seat faces and valve disk faces shall be made from corrosion and erosion resistant material.

## 5. Safety valve springs

**5.1 Helical coil**

**5.1.1** *Material.* Helical coil springs shall be made from circular section material complying with the requirements of one of the British Standards given in table 1. Table 1 also gives the temperature limits between which springs of the various materials shall be used.

NOTE. Recommended limiting sections for materials are also given in table 1.

**5.1.2** *Condition of material.* Bars or wires used in the unmachined condition shall be in accordance with the relevant British Standard. Where the relevant standard does not specify the maximum depth of surface defects and decarburization, the surface defects shall be limited to 1 % of bar diameter or 0.25 mm whichever is the greater, and decarburization shall be limited to 2 % of bar diameter or 0.30 mm whichever is the greater. No more than one-third of the total affected depth shall be complete decarburization.

When bars are machined, prior to hot or cold coiling into helical springs, they shall be free from all surface defects, there shall be no complete decarburization and partial decarburization shall not exceed 0.13 mm in depth.

**5.2 Torsion bar.** Torsion bar springs shall be made from steel which has a tensile yield stress not less than 1350 N/mm$^2$.

When selecting the material from which the spring is manufactured, due account shall be taken of the additional deflection and hence increased stresses which apply when the valve is fully lifted.

## 6. Bolting for pressure containing joints

The dimensions and finish of bolting shall comply with the following British Standards as appropriate.

| Metric | Inch |
|---|---|
| BS 3692 | BS 1768 (below ½ in) |
| BS 4190 | BS 1769 |
| BS 4439 | BS 2693 : Part 1 |
| BS 4882 | BS 2708 |
| | BS 4882 |

# Section three. Design and construction

## 7. General

**7.1 Design lift.** For safety valves that have a discharge area which is less than 80 % of the flow area, the overpressure at which the design lift is attained shall not exceed 10 % of the set pressure.

For safety valves that have a discharge area which is 80 % or more of the flow area, the overpressure at which the design lift is attained shall not exceed 5 % of the set pressure.

**7.2 Bore.** The bore of the body seat of each safety valve connected directly to a boiler shall be not less than 20 mm.

The minimum area of the inlet connection of the safety valve shall be not less than the minimum area of the body seat or, in the case of double safety valves, it shall be not less than the sum of the minimum areas of the body seats.

**7.3 Discharge.** Safety valves shall be so constructed that breakage of any part or failure of any device will not obstruct free and full discharge through the safety valves.

In the particular case of pilot operated safety valves, at least two independent pilot device systems shall be provided for each main safety valve. The two systems shall be connected individually and arranged such that failure of any one pilot device system shall not prejudice the correct functioning of the other system in controlling the main safety valve.

**7.4 Moving parts.** The valve disks and spindles:

(a) shall be guided efficiently, and

(b) shall have sufficient clearance to ensure freedom of movement under all conditions of service, and

(c) shall be prevented from lifting out of their seats.

Spindles shall not be fitted with stuffing boxes.

**7.5 Body seats.** Body seat faces shall be either:

(a) flat and at right angles to the axis of the body seat; or

(b) tapered, provided the included angle of the taper is not less than 90°.

Seats, other than those of integral design, shall be secured effectively.

**7.6 Prevention of alteration to the set pressure.** All safety valves shall be sealed by the manufacturer, his representative or a responsible authority. Unauthorized interference with the load on the spring, after the safety valve has been adjusted, shall be prevented by:

(a) the fitting of a ferrule under the adjusting screw collar, or

(b) the fitting of a compression ring under the adjusting screw collar, or

(c) the locking of the adjusting screw.

NOTE. Alternations should only be made with the authority of the manufacturer and/or the inspecting authority.

**7.7 Easing gear.** Safety valves shall be so arranged that, when they are under normal working pressure, the mechanical load on the valve head can be eased by means of suitable gear.

**7.8 Gagging device.** When a gagging device is provided, due account shall be taken of the suitability of the valve spindle to accept additional compressive loading arising from its use.

## 8. Scantlings

The design of a safety valve body shall be such that the safety valve body is sufficiently robust to withstand reaction loads which will be imposed in service.

Steel valves manufactured in accordance with this Part of BS 6759 shall only be deemed to comply with this Part of BS 6759 if the design strength value does not exceed that given in table 2.3 of BS 5500 : 1982. Valves shall be designed for a life of 150 000 h except when contractual requirements, approved by the inspecting authority, specify a different design life.

Calculations of scantlings shall be based on the design pressure as defined in BS 806 and BS 2790 or, the calculation pressure as defined in BS 1113, as appropriate.

End connections shall comply with one of the following standards:

(a) flanges with BS 1560 : Part 2 or BS 4504;

(b) screwed connections with BS 21;

(c) weld preparation with an appropriate standard which has the approval of the inspecting authority.

## 9. Castings

All castings shall be smooth, sound, and free from cracks, significant flaws or other injurious defect. Variations in thickness shall be gradual, and substantial fillets shall be provided.

The welding of cast steel pressure containing components shall be in accordance with the procedures laid down in BS 4570 : Part 1, cognizance being taken of the requirements of clauses **18** and **19** of BS 1504 : 1976 dealing with rectification of castings and freedom from defects, respectively.

The welding of cast iron or copper alloy pressure containing components is prohibited.

## 10. Forgings

All forgings shall comply with BS 1503.

## 11. Springs

### 11.1 Helical coil

**11.1.1** *General.* The spring manufacturer shall be in a position, if so requested, to supply a certificate stating that the spring or springs have been made from the prescribed material, and have been tested in accordance with the requirements of this British Standard.

**11.1.2** *Dimensions.* The proportion of unloaded length to external diameter of the spring shall not exceed 4 to 1.

**11.1.3** *Stress.* The shear stress, $q$, shall not exceed the value for that particular material given in column 4 of table 1, subject to the maximum shear stress when the spring is compressed coil to coil not exceeding the value given in column 5 of that table for the same material.

$q$ shall be determined from the following equation.

$$q = \frac{8\,WDKA}{\pi d^3} \qquad (1)$$

where

$q$ is the shear stress (in N/mm²);

$W$ is the force at set pressure (in N);

$D$ is the mean diameter of the coil (in mm);

$d$ is the diameter of the section (in mm);

$K$ is the safety valve spring correction factor (see figure 2)

$$= \frac{D/d + 0.2}{D/d - 1};$$

$$A = \frac{\delta_1 + \delta_2}{\delta_1} \qquad (2)$$

where

$\delta_1$ is the axial deflection due to force W (in mm);

$\delta_2$ is the lift (in mm) of the valve at certified discharge capacity.

**11.1.4** *Tests.* Springs shall show no further permanent set after being compressed solid six times by a quick acting scrag.

NOTE. Any further tests applied to springs should be agreed between the valve maker and the spring maker, preferably in accordance with the recommendations given in BS 1726 : Part 1.

**11.1.5** *Workmanship.* The pitch of the coils shall be regular. The ends of the springs shall present a flat bearing of between 270° and 300° of the circumference at right angles to the axis, so that when placed on end on a horizontal plane the springs shall be within the tolerances for class A springs recommended in appendix A of BS 1726 : Part 1 : 1964.

NOTE. If it is essential to specify tolerances closer than those recommended in BS 1726 : Part 1, these should be agreed between the valve maker and the spring maker.

**11.1.6** *Spacing of coils.* The spacing of the coils shall be such that when the valve head is at the lift corresponding to its certified discharge capacity the space between the coils shall be not less than 1 mm.

**11.1.7** *Number of working coils.* The number of working or free coils in a spring, $n$, shall be determined from the following equation.

$$n = \frac{d^4 G \delta_1}{8 D^3 W} \qquad (3)$$

where

$G$ is the shear modulus (in N/mm²); (see table 1, column 6);

$n$ is the number of working coils.

Other symbols used in the above equation are defined in **11.1.3.**

**11.2 Torsion bar.** The shear stress in the springs, when the safety valve is loaded to its set pressure, shall not exceed 550 N/mm² when calculated in accordance with the following equation.

$$q = \frac{16 T}{\pi d^3} \qquad (4)$$

where

$q$ is the shear stress (in N/mm²);

$T$ is the torque (in N·mm);

$d$ is the bar diameter (in mm).

**Table 1. Helical coil spring materials and mechanical properties**

| Material | | Recommended limiting section (diameter) | Spring temperature range for which the material is suitable | Shear stress $q$ calculated from equation (1) | Maximum shear stress spring coil to coil | Shear modulus $G$ |
|---|---|---|---|---|---|---|
| | | mm | °C | N/mm² | N/mm² | N/mm² |
| BS 2803 094A65 HS | | Up to 10* | −20 to +150 | 485 | 765 | 80 000 |
| BS 5216 HS2 and HS3 | | Up to 10* | −20 to +130 | 425 | 670 | 80 000 |
| BS 970 : Part 5 | 070A72 | 10 to 20 | | | | |
| | 070A78 | | | | | |
| | 250A58 | 10 to 40 | −20 to +150 | | | |
| | 250A61 | | | | | |
| | 527A60 | 10 to 80 | | 540 | 860 | 80 000 |
| | 735A50 | 10 to 80 | −20 to +175 | | | |
| | 805A60 | 10 to 80 | −40 to +150 | | | |
| BS 2803 735A50 HS | | Up to 10* | −20 to +175 | 525 | 830 | 80 000 |
| BS 2056 302S26<br>316S42 | | Up to 10* | −200 to +250 | 415 | 655 | 70 000 |

* For springs made from wire of up to and including 5 mm diameter, where satisfactory operation and repeatability of set pressure can be confirmed during safety valve operational characteristics tests using steam, it is permissible to design the spring so that the shear stress $q$, calculated from equation (1) does not exceed 38 % of the minimum ultimate tensile strength, and the maximum shear stress, spring coil to coil, does not exceed 60 % of the minimum ultimate tensile strength.

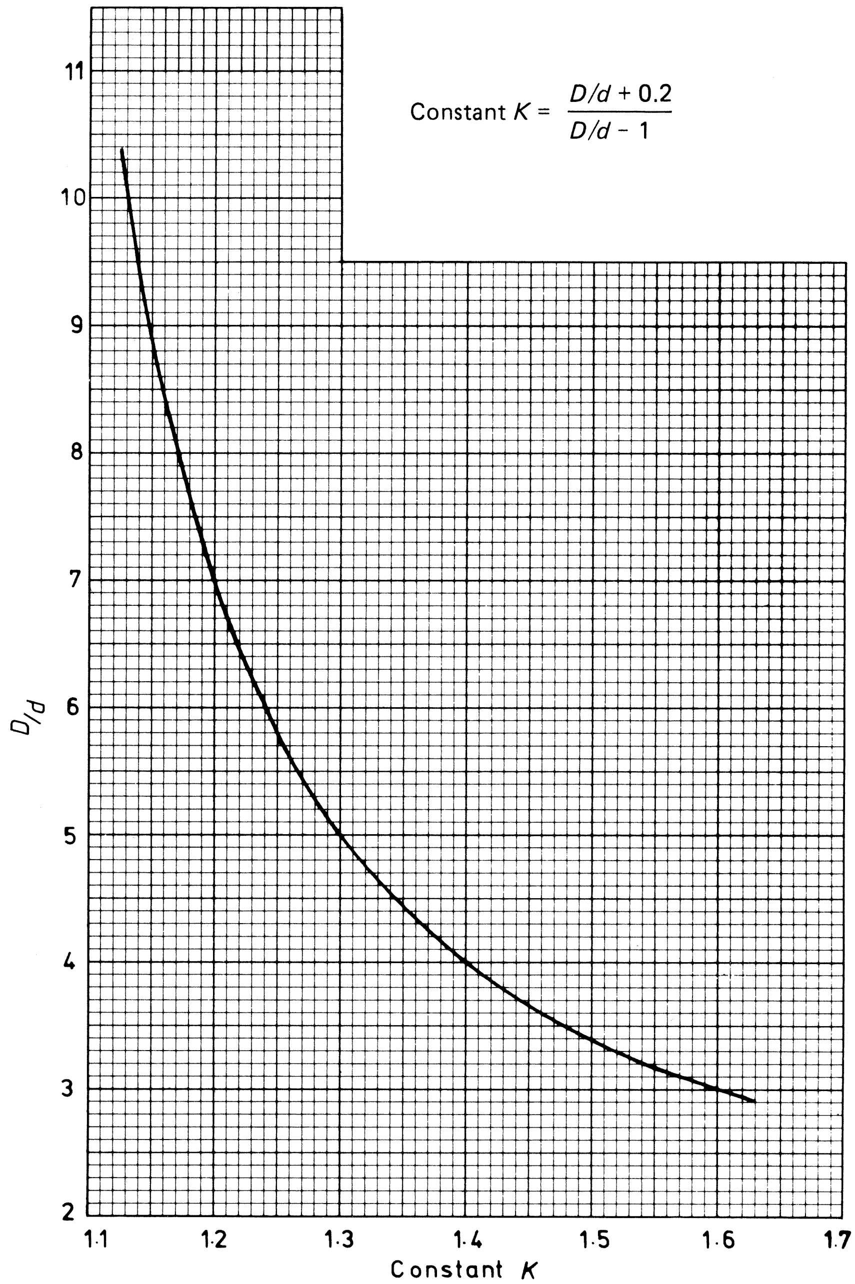



**Figure 2. Graph for value of constant $K$, the safety valve spring correction factor** (see **11.1.3**)

## Section four. Production testing and inspection

### 12. General

All temporary pipes, connections and blanking devices shall be adequate to withstand the test pressure.

Any temporary welded-on attachments shall be carefully removed after the test, and the resulting weld scars shall be ground flush with the parent metal. After grinding, all such scars shall be inspected by magnetic particle or liquid penetrant techniques in accordance with BS 4080 to ensure that no injurious defects remain.

To confirm accuracy, all Bourdon tube pressure gauges or other recognized pressure measuring devices fitted to test equipment shall be tested and calibrated at intervals of time no greater than six months.

### 13. Safety precautions

The safety valve shall be properly vented to remove entrapped air. No safety valve or part thereof undergoing pressure testing shall be subjected to any form of shock loading, e.g. hammer testing.

If materials that are liable to failure by brittle fracture are incorporated into that part of the safety valve which is to be hydraulically tested, then both the safety valve or part thereof and the testing medium shall be at a sufficient temperature to prevent the possibility of such failure.

### 14. Test media

The test media shall be water (treated with a suitable inhibitor, when necessary), or other liquid whose viscosity at ambient temperature is equal to or less than water.

NOTE. Attention is drawn to the need to control the chloride content of the test water in the case of valves with austenitic steel components.

For the setting of safety valve cold differential test pressure, the test medium shall be either water or air or other gas, provided that the safety valve has been subjected to the shell test as specified in **15.1**.

For the setting of set pressure, the test medium shall be steam at the appropriate pressure.

## 15. Hydraulic test

**15.1 Shell test.** The body seat of safety valves shall be blanked off and a test pressure of 1.5 times the maximum pressure for which the safety valve is designed shall be applied only to the part of the body at the inlet side of the seat.

Safety valves to be installed with a free discharge, or where the only back pressure is built-up back pressure, do not require a hydraulic test to be applied to that part of the valve on the discharge side of the seat. In the case of safety valves subjected to a superimposed back pressure, or valves on closed discharge systems (closed bonnet valves), then a hydraulic test of 1.5 times the maximum back pressure on the valve shall be applied to those parts on the discharge side of the seat.

**15.2 Duration of hydraulic test.** The shell test pressure shall be applied to the safety valve, and maintained at the required pressure for a sufficient length of time to permit a visual examination to be made of all surfaces and joints, but in any case not less than the times detailed in table 2. For shell tests on the discharge side of the seat of safety valves, the testing time shall be based on the pressure specified in **15.1** and the discharge size.

NOTE. Testing times listed in table 1 differ from those given in British Standards for general purpose valves in that they are expressed in minutes.

## Section five. Marking

## 16. Body marking

Each safety valve shall bear legible and durable marking on the body or on a plate fixed securely to the body. If a plate is used, it shall be separate and distinct from the identification plate referred to in clause **17**. Body markings shall be as follows:

(a) the inlet nominal size (DN) or in the case of double safety valves 2 × DN;

(b) for all materials except copper alloy and cast iron, the material designation of the body;

(c) the manufacturer's name and/or trademark;

(d) an arrow showing the direction of flow, where the inlet and outlet connections have the same dimension or the same nominal pressure;

(e) the ring joint number where applicable (to be marked on the flange).

## 17. Identification plate

The following information, stating units, shall be on an identification plate securely fixed to the safety valve:

(a) the limiting operating temperature(s) (in °C) for which the valve has been designed, where applicable;

(b) the set pressure, in bar gauge;

(c) the number of this British Standard, i.e. BS 6759 : Part 1 : 1984†;

**Table 2. Minimum duration of hydraulic shell test**

| Nominal valve size (DN)* | Pressure rating: Up to and including 40 bar | Over 40 bar, up to and including 64 bar | Over 64 bar |
|---|---|---|---|
| | Duration | | |
| | min | min | min |
| Up to and including 50 | 2 | 2 | 3 |
| over 50 up to and including 65 | 2 | 2 | 4 |
| over 65 up to and including 80 | 2 | 3 | 4 |
| over 80 up to and including 100 | 2 | 4 | 5 |
| over 100 up to and including 125 | 2 | 4 | 6 |
| over 125 up to and including 150 | 2 | 5 | 7 |
| over 150 up to and including 200 | 3 | 5 | 9 |
| over 200 up to and including 250 | 3 | 6 | 11 |
| over 250 up to and including 300 | 4 | 7 | 13 |
| over 300 up to and including 350 | 4 | 8 | 15 |
| over 350 up to and including 400 | 4 | 9 | 17 |
| over 400 up to and including 450 | 4 | 9 | 19 |
| over 450 up to and including 500 | 5 | 10 | 22 |
| over 500 up to and including 600 | 5 | 12 | 24 |

* Nominal valve sizes larger than DN 600 shall have testing times pro rata.

† Marking BS 6759 : Part 1 : 1984 on or in relation to a product is a claim by the manufacturer that the product has been manufactured to the requirements of the standard. The accuracy of such a claim is therefore solely the manufacturer's responsibility. Enquiries as to the availability of third party certification to support such claims should be addressed to the Director, Quality Assurance Division, BSI, Maylands Avenue, Hemel Hempstead, Herts HP2 4SQ for certification marks administered by BSI or to the appropriate authority for other certification marks.

(d) the manufacturer's type reference;

(e) the derated coefficient of discharge or certified discharge capacity (stating units) indicating the reference fluid: G for gas, S for steam and L for liquid.

NOTE. The designation letter may be placed either before or after the derated coefficient of discharge or certified discharge capacity, e.g. G-0.815 or G-100 000 kg/h.

(f) the flow area in square millimetres;

(g) the minimum lift, in millimetres, and corresponding overpressure expressed as a percentage of set pressure;

(h) the design life, if other than 150 000 h.

NOTE. A manufacturer, having complied with the requirements of clauses **16** and **17**, is not precluded from marking any item additionally in a place other than that specified, e.g. if a marking is required to appear on the body it may also be repeated on an identification plate.

Additional markings may be used at the option of the manufacturer, e.g. a serial number or catalogue number, providing they do not conflict with any of the specified markings.

## Section six. Performance testing

### 18. Type testing of safety valves for operating and flow characteristics using water, steam, air or other gas

**18.1 General**

**18.1.1** *Application.* This clause applies to the types of safety valves defined in **2.1**.

**18.1.2** *Carrying out of tests.* The tests to determine the operating characteristics shall be in accordance with clause **19** and the tests to determine the flow characteristics shall be in accordance with clause **20**.

When these tests are carried out separately, the parts of the valve which influence fluid flow shall be complete and installed in the valve.

All testing shall be witnessed by a representative(s) of the independent authority or authorities.

**18.2 Testing facilities.** Type testing in accordance with the requirements of this clause shall only be carried out at establishments approved by the independent authority or authorities*.

**18.3 Object of tests.** The object of the tests is to determine, under specific operating conditions, particular characteristics of the valves before opening, while discharging and at closing. As a minimum these are:

(a) set pressure;

(b) reseating pressure;

(c) blowdown;

(d) reproducibility of valve performance;

(e) mechanical characteristics of the valves, determined visually or aurally, such as:

ability to re-seat satisfactorily;

absence or presence of chatter, flutter, sticking and/or harmful vibration;

(f) relieving pressure;

(g) lift at the appropriate overpressure.

**18.4 Procedure for testing.** The purpose and manner of testing shall be such as to provide suitable data from which the operational and flow characteristics are determined.

To this end the following information shall be supplied to the independent authority, and shall be approved before testing is undertaken:

(a) full particulars of the valves to be tested and the range of valves and springs which they represent;

(b) details of the test rig(s) including proposed instrumentation test and calibration procedure;

(c) the proposed source, capacity, pressure, temperature and properties of the test fluid(s).

**18.5 Results calculated from test.** The theoretical flowing capacity shall be calculated (see **21.2**, **21.3** or **21.4**) and, using this value together with the actual flowing capacity at relieving pressure, the coefficient of discharge of the safety valve shall be calculated (see **21.1**).

### 19. Tests to determine operating characteristics

**19.1 Carrying out of tests.** The set pressures at which the operating characteristics are determined shall be the minimum set pressures for which the spring used is designed. Valves designed to discharge steam shall be tested on dry saturated steam. Valves designed to discharge water shall be tested on water. The allowable tolerances or limits, as applicable, on these characteristics are as follows:

(a) Set pressure (applicable to steam and water valves):

| | |
|---|---|
| below 5 bar | ± 0.14 bar |
| 5 bar up to 20 bar | ± 3 % |
| 20 bar up to 100 bar | ± 2 % |
| 100 bar and above | ± 1½ % |

(b) Lift (applicable to steam and water valves); ± 5 % of the average for a given size of valve.

(c) Adjustable blowdown (steam valves only): 2.5 % of set pressure, minimum; 5 % of set pressure, maximum, except for valves:

(1) of the high discharge capacity type designed specifically for blowdown of up to 10 % of set pressure;

(2) having values of set pressure less than 3.0 bar when the blowdown shall be a maximum of 0.3 bar.

(d) Non-adjustable blowdown (steam valves only): maximum 15 % of set pressure.

(e) Non-adjustable blowdown (water valves only): minimum 2.5 % of set pressure: maximum 20 % of set pressure. For valves of set pressure less than 3 bar, the blowdown shall be a maximum of 0.6 bar.

**19.2 Test equipment.** The error of pressure measuring equipment used during the test shall be not more than 0.5 % of the full scale reading, with the test pressure within the middle third of the instrument range.

**19.3 Valves used in the test programme.** The safety valves tested shall be representative of the design, pressure, and size range of valves for which operating characteristics are required. To be representative, the ratio of valve inlet to flow area and the ratio of flow area to valve outlet shall be taken into account.

Tests shall be carried out on three sizes unless the size range contains not more than six sizes, when it is permissible to reduce the number tested to two. When the range is extended from a number less than seven to a number equal to or in excess of seven, then tests on three sizes of valves shall be carried out.

* Document 83/71897 is a schedule of potential safety valve testing facilities in the UK. Copies are available from the Enquiry Section (London), British Standards Institution.

When the range is extended so that the previously tested safety valves are no longer representative of the range, further tests shall be carried out.

**19.4 Test procedure.** The tests shall be carried out using three significantly different springs for each size of valve. Where three test pressures are required from one valve size, it is permissible to test either one valve with three significantly different springs or three valves of the same size at three significantly different settings in order to comply with the requirements. Each test shall be carried out a minimum of three times in order to establish and confirm acceptable reproducibility of performance.

For the case of valves of either novel or special design, of which one size only at one pressure rating is being manufactured, tests at that set pressure shall be carried out.

For the case of valves of which one size only at various pressure ratings is being manufactured, tests shall be carried out using four different springs which shall cover the range of pressure for which the valve shall be used.

## 20. Tests to determine flow characteristics

**20.1 Carrying out of tests.** For steam safety valves, after operational characteristics have been established satisfactorily using steam as the test fluid, it is acceptable to use steam, air, or another gas of known characteristics as the fluid for flow characteristics tests. When discharged quantities are being assessed using fluids other than steam the valve disk shall be mechanically held at the same lift as that obtained with steam at the same overpressure.

For water safety valves, after operational characteristics have been satisfactorily established using water as the test fluid, it is acceptable to use other liquids of similar viscosity for flow characteristics tests.

It is NOT permissible to use steam, air, or other gas for the flow characteristics testing of a water safety valve, nor water nor any other liquid for the flow characteristics testing of a steam safety valve.

**20.2 Valves used in the test programme**

**20.2.1** *Representative valves.* The safety valves tested shall be representative of the design, pressure and size range of valves for which flow characteristics are required.

**20.2.2** *Size range and number of valves to be tested.* Tests shall be carried out on three sizes unless the size range contains not more than six sizes, when it is permissible to reduce the number tested to two. When the range is extended from a number less than seven to a number equal to or in excess of seven, then tests on three sizes of valves shall be carried out.

When the range is extended so that the previously tested safety valves are no longer representative of the range, further tests shall be carried out.

NOTE. If the size range comprises one only, see **20.3.3**.

**20.3 Test procedure**

**20.3.1** *Tests on each valve.* On each of the valves to be tested, as required by **20.2.2**, flow characteristics tests for the determination of the coefficient of discharge shall be carried out at three different pressures.

In all cases the size and pressure range shall be representative of the design range within the limits of the testing facility.

In those cases where the size of the valve is greater than can be tested at the test facility, the independent authority shall, at its discretion, subject to feasibility and opportunity, require one confirmatory flow test at the location of the installation and require the proper function of at least one valve of the design to be demonstrated by test.

NOTE. Three geometrically similar models of different sizes may be used to determine the coefficient of discharge.

**20.3.2** *Test techniques.* The test techniques adopted shall be either of the following.

(a) The valve configuration shall be the same as that used during the tests for operational characteristics; i.e. the lift and, if a blowdown ring(s) is fitted, its position shall be the one(s) established for the particular size and overpressure during operational testing.

Average values of lift shall be used when the tolerances of **19.1** have been met. Attention is also drawn to the requirements of **20.4**.

or

(b) The valve configuration shall be varied in respect of lift and/or the position of blowdown ring(s) where such is fitted.

NOTE. Technique (a) is used where it is desired to derive from the test results the coefficient of discharge of a given configuration of safety value at a given overpressure.

Technique (b) is used where it is desired to derive from test results, usually plotted as a series of curves, the appropriate coefficient of discharge of a safety valve for various combinations of overpressure, lift and the position of blowdown ring(s).

**20.3.3** *Tests on valves of novel or special design.* In the case of valves of either novel or special design of which one size only for various pressures is being manufactured, tests shall be carried out at four different set pressures which shall cover the range of pressure for which the valve will be used or as determined by the limits of the test facility.

The discharge capacities as determined by these four tests shall be plotted against the absolute inlet pressure, and a straight line drawn through these four points and zero-zero.

For liquids, the capacities as determined by the four tests shall be plotted on log-log paper against the differential (inlet pressure minus back pressure) test pressure, and a straight line drawn through these four points. If all points do not lie within ± 5 % of this line, additional testing shall be carried out until the line is established without ambiguity.

**20.3.4** *Test results.* In all methods described for flow characteristics testing, all final results shall be within ± 5 % of the average, or additional testing shall be carried out until this criterion is met.

Where test technique (b) of **20.3.2** has been adopted, the results obtained shall be plotted as curves to obtain the unique value of discharge capacity of a valve at a given overpressure and which has the blowdown ring(s) at a given setting.

**20.4 Adjustments during test.** No adjustment to the valve shall be made during the test. Following any change or deviation of the test conditions, a sufficient period of time shall be allowed to permit the rate of flow, temperature and pressure to reach stable conditions before readings are taken.

**20.5 Records of tests.** The test records shall include all observations, measurements, instrument readings and instrument calibration records for the objective(s) of the test. Original test records shall remain in the custody of the test establishment which conducted the test. Copies of all test records shall be furnished to each of the parties concerned with the test. Corrections and corrected values shall be entered separately in the test record.

**20.6 Flow test equipment.** The test equipment shall be designed and operated in such a way that the actual test flowing capacity measurement shall be accurate to within ± 2 %.

**20.7 Coefficient of discharge.** The coefficient of discharge shall be determined as specified in clause **21**.

**20.8 Certification of valves.** The certified discharge capacity of the valve shall be 0.9 of the capacity determined by test. For valves using the coefficient of discharge method, the certified discharge capacity shall be 0.9 of the theoretical capacity times the coefficient of discharge (i.e. the derated coefficient of discharge).

The coefficient of discharge shall not be used to calculate the capacity at a lower overpressure than that at which the test was carried out (see **20.3**) although it can be used to calculate the capacity at a higher overpressure.

The actual capacity for a back pressure above the test back pressure condition and/or for sub-critical flow shall only be established by test.

NOTE. Valves having a certified coefficient of discharge established on critical flow at the test back pressure may not have the same coefficient of discharge at a higher back pressure. Calculations for equivalent capacities for sub-critical flow will result in a theoretical capacity equivalence only.

## 21. Determination of coefficient of discharge and certified discharge capacity

**21.1 Coefficient of discharge.** The coefficient of discharge, $K_d$, shall be calculated from the following equation:

$$K_d = \frac{\text{actual flowing capacity (from test)}}{\text{theoretical flowing capacity (from calculation)}} \quad (5)$$

The derated coefficient of discharge, $K_{dr}$, shall be calculated from the following equation:

$$K_{dr} = K_d \times 0.9 \quad (6)$$

**21.2 Theoretical flowing (discharge) capacity using dry saturated steam as the test medium.** Dry saturated steam in this context means steam with a minimum dryness fraction of 0.98 or a maximum degree of superheat of 10 °C.

For applications where the value of $p$ is up to and including 110 bar:

$$q_m = 0.525p \quad (7)$$

For applications where the value of $p$ is over 110 bar and up to 220 bar:

$$q_m = 0.525p \left(\frac{2.7644p - 1000}{3.3242p - 1061}\right) \quad (8)$$

where

$q_m$ is the theoretical flowing capacity of dry saturated steam (in kg/h per mm$^2$ of flow area);

$p$ is the actual flowing (inlet) pressure, {(set pressure × 1.1) + 1} (in bar absolute).

NOTE. It has been appreciated for many years that there is a significant divergence between the maximum isentropic steam flow and Napier flow at pressures above 110 bar such that at 221 bar the divergence approaches 18 %. To rectify this significant understatement of capacity with increasing pressure, a correction factor is included in equation (8).

**21.3 Theoretical flowing (discharge) capacity using air or any gas as the test medium**

**21.3.1** *Critical and sub-critical flow*

NOTE. The flow of gas or vapour through an orifice increases as the downstream pressure is decreased until critical flow is achieved. Further decrease of the downstream pressure does not result in any further increase of flow.

Critical flow occurs when:

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

Sub-critical flow occurs when:

$$\frac{p_b}{p} \text{ is greater than } \left(\frac{2}{k+1}\right)^{k/(k-1)}$$

where the validity of Rankine's law is assumed and where

$p$ is the actual relieving pressure {(set pressure × 1.1) + 1} (in bar absolute);

$p_b$ is the back pressure (in bar absolute);

$k$ is the isentropic coefficient at the relieving inlet conditions (for a perfect gas $k$ is taken as the ratio of specific heats).

**21.3.2** *Theoretical flowing (discharge) capacity at critical flow.* Where the validity of Rankine's law is assumed, the theoretical flowing (discharge) capacity, $q_m$, at critical flow shall be calculated from the following equation.

$$q_m = pC\sqrt{\frac{M}{ZT}} \quad (9)$$

$$= 0.2883\, C\sqrt{\frac{p}{v}}$$

where

$q_m$ is the theoretical flowing capacity (in kg/h per mm$^2$ of flow area);

$C$ is a function of the isentropic coefficient $k$ (for rounded figures see table 3)

$$= 3.948\sqrt{k\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}} \quad (10)$$

$p$ is the actual relieving pressure (in bar absolute);

$v$ is the specific volume at the actual relieving pressure and relieving temperature (in m$^3$/kg);

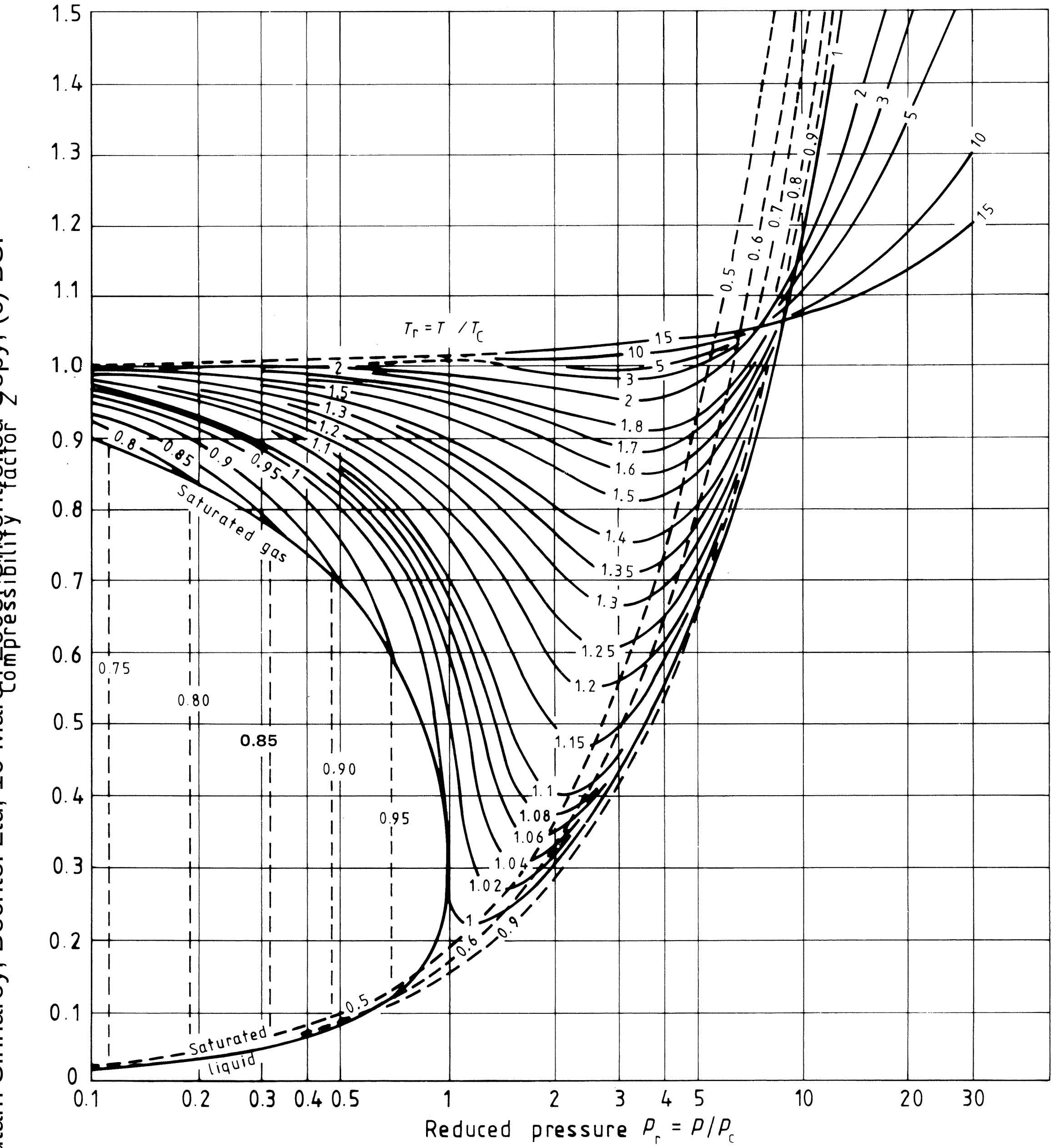
$M$ is the molecular mass of the gas (in kg/kmol);

$T$ is the absolute temperature at the inlet (in K);

$Z$ is the compressibility factor. In many cases it is unity and may be neglected. (See figure 3.)

**Table 3. Values of *C* relative to values of *k***

| *k* | *C* | *k* | *C* | *k* | *C* | *k* | *C* | *k* | *C* | *k* | *C* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.40 | 1.65 | 0.84 | 2.24 | 1.02 | 2.41 | 1.22 | 2.58 | 1.42 | 2.72 | 1.62 | 2.84 |
| 0.45 | 1.73 | 0.86 | 2.26 | 1.04 | 2.43 | 1.24 | 2.59 | 1.44 | 2.73 | 1.64 | 2.85 |
| 0.50 | 1.81 | 0.88 | 2.28 | 1.06 | 2.45 | 1.26 | 2.61 | 1.46 | 2.74 | 1.66 | 2.86 |
| 0.55 | 1.89 | 0.90 | 2.30 | 1.08 | 2.46 | 1.28 | 2.62 | 1.48 | 2.76 | 1.68 | 2.87 |
| 0.60 | 1.96 | 0.92 | 2.32 | 1.10 | 2.48 | 1.30 | 2.63 | 1.50 | 2.77 | 1.70 | 2.89 |
| 0.65 | 2.02 | 0.94 | 2.34 | 1.12 | 2.50 | 1.32 | 2.65 | 1.52 | 2.78 | 1.80 | 2.94 |
| 0.70 | 2.08 | 0.96 | 2.36 | 1.14 | 2.51 | 1.34 | 2.66 | 1.54 | 2.79 | 1.90 | 2.99 |
| 0.75 | 2.14 | 0.98 | 2.38 | 1.16 | 2.53 | 1.36 | 2.68 | 1.56 | 2 80 | 2.00 | 3.04 |
| 0.80 | 2.20 | 0.99 | 2.39 | 1.18 | 2.55 | 1.38 | 2.69 | 1.58 | 2.82 | 2.10 | 3.09 |
| 0.82 | 2.22 | 1.001 | 2.40 | 1.20 | 2.56 | 1.40 | 2.70 | 1.60 | 2.83 | 2.20 | 3.13 |




$p_r = p/p_c$

$T_r = T/T_c$

where

$p$ is the actual relieving pressure (in bar, absolute);

$T$ is the relieving temperature (in K);

$p_c$ is the critical pressure of the pure gas (in bar absolute);

$T_c$ is the critical temperature of the pure gas (in K).

**Figure 3. Compressibility factor *Z* as a function of reduced pressure $p_r$ and reduced temperature $T_r$**

**21.3.3** *Theoretical flowing (discharge) capacity at sub-critical flow.* The theoretical flowing (discharge) capacity, $q_m$, at sub-critical flow shall be calculated from the following equation.

$$q_m = pCK_b\sqrt{\frac{M}{ZT}} \quad (11)$$

$$= 0.2883\, CK_b \sqrt{\frac{p}{v}}$$

where

$$K_b = \sqrt{\frac{\frac{2k}{k-1}\left[\left(\frac{p_b}{p}\right)^{2/k} - \left(\frac{p_b}{p}\right)^{(k+1)/k}\right]}{k\left(\frac{2}{k+1}\right)^{(k+1)/(k-1)}}} \quad (12)$$

(for rounded figures see table 4)

**21.4 Theoretical flowing (discharge) capacity using a liquid as the test medium.** The theoretical flowing (discharge) capacity, $q_m$, shall be calculated from the following equation.

$$q_m = 1.61\sqrt{\rho\,\Delta p} \quad (13)$$

where

$q_m$ is the theoretical flowing capacity related to the smallest flow area in kg/h per mm² of flow area;

$\Delta p$ is the pressure drop (in bar), i.e. $p - p_b$;

$p$ is the actual flowing (inlet) pressure, {(set pressure × 1.1) + 1} (in bar absolute);

$p_b$ is the back pressure (in bar, absolute);

$\rho$ is the volumetric mass (in kg/m³).

**21.5 Certified discharge capacity**

**21.5.1** *General.* The certified discharge capacity of the safety valve shall be stated at an overpressure of 110 % of the set pressure. In the case of a supplementary loaded safety valve (see **2.1.3**), in the event of a supplementary loading not being released, the valve shall be designed such that it shall pass its certified discharge capacity, at a pressure not exceeding 115 % of the set pressure.

The safety valve certified discharge capacity shall be calculated using equations (14) to (18). Where the feed-water temperature, and hence the actual evaporative capacity of a boiler is not known, the required safety valve area shall be based on the specific peak load evaporation 'from and at 100 °C'.

NOTE. The term 'from and at 100 °C' is an abbreviation indicating the evaporation from feedwater at 100 °C to steam at 100 °C and as such is the basis of determining the peak load equivalent evaporation of a steam boiler.

**21.5.2** *Dry saturated steam.* Dry saturated steam in this context means steam with a minimum dryness fraction of 0.98 or a maximum degree of superheat of 10 °C.

For applications where the value of $p$ is up to and including 110 bar:

$$E = 0.525\, pAK_{dr} \quad (14)$$

For applications where the value of $p$ is over 110 bar and up to 220 bar:

$$E = 0.525\, p\left(\frac{2.7644\,p - 1000}{3.3242\,p - 1061}\right)AK_{dr} \quad (15)$$

where

$E$ is the certified discharge capacity of dry saturated steam (in kg/h);

$p$ is the actual relieving pressure {(set pressure × 1.1) + 1} (in bar, absolute);

$A$ is the flow area (in mm²);

$K_{dr}$ is the derated coefficient of discharge (see equation (6)).

**21.5.3** *Wet steam.* The certified discharge capacity of a safety valve which discharges wet steam of dryness fraction 0.9 and over, $E_w$, shall be calculated using the following equation.

$$E_w = \frac{E}{x} \quad (16)$$

where

$E_w$ is the certified discharge capacity of wet steam (in kg/h);

$E$ is the certified discharge capacity of dry saturated steam calculated using equation (14) or (15) (in kg/h);

$x$ is the dryness fraction of steam at the safety valve inlet.

Equation (16) shall not be used where the dryness fraction is below 0.9.

**21.5.4** *Superheated steam.* The certified discharge capacity of a safety valve which discharges superheated steam, $E_{Sh}$, shall be calculated using the following equation.

$$E_{Sh} = EK_{Sh} \quad (17)$$

where

$E_{Sh}$ is the certified discharge capacity of superheated steam (in kg/h);

$E$ is the certified discharge capacity of dry saturated steam calculated using equation (14) or (15) (in kg/h);

$K_{Sh}$ is the superheat correction factor obtained from table 5.

**21.5.5** *Hot water.* The rating of a safety valve mounted on a fully-flooded hot water boiler not covered by BS 779 or BS 855 shall be calculated using the following equation.

$$R = 0.329\, pAK_{dr} \quad (18)$$

where

$R$ is the rating of a safety valve (in kW)*;

$p$ is the actual relieving pressure (in bar, absolute);

$A$ is the flow area (in mm²);

$K_{dr}$ is the derated coefficient of discharge.

NOTE. It is recommended that the set pressure of the safety valve(s) be not less than 10 % above the boiler operating pressure with a minimum of 1.3 bar to prevent unnecessary lifting of the safety valve(s).

* The kW, while not being the usual unit for the rating of a safety valve, has been used because the rated output of a hot water boiler is given in kW in the appropriate standards, and for ease in selecting the correct complement of safety valves, identical units are essential.

**Table 4. Capacity correction factors for back pressure ($K_b$)**

| $p_b/p$ \ $k$ | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.001 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 | 2.0 | 2.1 | 2.2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.45 | | | | | | | | | | | | | | | | | 1.000 | 0.999 | 0.999 |
| 0.50 | | | | | | | | | | | | | 1.000 | 0.999 | 0.998 | 0.996 | 0.994 | 0.992 | 0.989 |
| 0.55 | | | | | | | | | | 1.000 | 0.999 | 0.997 | 0.994 | 0.991 | 0.987 | 0.983 | 0.979 | 0.975 | 0.971 |
| 0.60 | | | | | | | | 0.999 | 0.997 | 0.993 | 0.989 | 0.983 | 0.978 | 0.972 | 0.967 | 0.961 | 0.955 | 0.950 | 0.945 |
| 0.65 | | | | | | 0.999 | 0.995 | 0.989 | 0.982 | 0.974 | 0.967 | 0.959 | 0.951 | 0.944 | 0.936 | 0.929 | 0.922 | 0.915 | 0.909 |
| 0.70 | | | | 0.999 | 0.993 | 0.985 | 0.975 | 0.964 | 0.953 | 0.943 | 0.932 | 0.922 | 0.913 | 0.903 | 0.895 | 0.886 | 0.879 | 0.871 | 0.864 |
| 0.75 | | 1.000 | 0.995 | 0.983 | 0.968 | 0.953 | 0.938 | 0.923 | 0.909 | 0.896 | 0.884 | 0.872 | 0.861 | 0.851 | 0.841 | 0.832 | 0.824 | 0.815 | 0.808 |
| 0.80 | 0.999 | 0.985 | 0.965 | 0.942 | 0.921 | 0.900 | 0.881 | 0.864 | 0.847 | 0.833 | 0.819 | 0.806 | 0.794 | 0.783 | 0.773 | 0.764 | 0.755 | 0.747 | 0.739 |
| 0.82 | 0.992 | 0.970 | 0.944 | 0.918 | 0.894 | 0.872 | 0.852 | 0.833 | 0.817 | 0.801 | 0.787 | 0.774 | 0.763 | 0.752 | 0.741 | 0.732 | 0.723 | 0.715 | 0.707 |
| 0.84 | 0.979 | 0.948 | 0.917 | 0.888 | 0.862 | 0.839 | 0.818 | 0.799 | 0.782 | 0.766 | 0.752 | 0.739 | 0.727 | 0.716 | 0.706 | 0.697 | 0.688 | 0.680 | 0.672 |
| 0.86 | 0.957 | 0.919 | 0.884 | 0.852 | 0.825 | 0.800 | 0.779 | 0.759 | 0.742 | 0.727 | 0.712 | 0.700 | 0.688 | 0.677 | 0.667 | 0.658 | 0.649 | 0.641 | 0.634 |
| 0.88 | 0.924 | 0.881 | 0.842 | 0.809 | 0.780 | 0.755 | 0.734 | 0.714 | 0.697 | 0.682 | 0.668 | 0.655 | 0.644 | 0.633 | 0.624 | 0.615 | 0.606 | 0.599 | 0.592 |
| 0.90 | 0.880 | 0.831 | 0.791 | 0.757 | 0.728 | 0.703 | 0.681 | 0.662 | 0.645 | 0.631 | 0.617 | 0.605 | 0.594 | 0.584 | 0.575 | 0.566 | 0.558 | 0.551 | 0.544 |
| 0.92 | 0.820 | 0.769 | 0.727 | 0.693 | 0.664 | 0.640 | 0.619 | 0.601 | 0.585 | 0.571 | 0.559 | 0.547 | 0.537 | 0.527 | 0.519 | 0.511 | 0.504 | 0.497 | 0.490 |
| 0.94 | 0.739 | 0.687 | 0.647 | 0.614 | 0.587 | 0.565 | 0.545 | 0.528 | 0.514 | 0.501 | 0.489 | 0.479 | 0.470 | 0.461 | 0.453 | 0.446 | 0.440 | 0.434 | 0.428 |
| 0.96 | 0.628 | 0.579 | 0.542 | 0.513 | 0.489 | 0.469 | 0.452 | 0.438 | 0.425 | 0.414 | 0.404 | 0.395 | 0.387 | 0.380 | 0.373 | 0.367 | 0.362 | 0.357 | 0.352 |
| 0.98 | 0.462 | 0.422 | 0.393 | 0.371 | 0.352 | 0.337 | 0.325 | 0.314 | 0.305 | 0.296 | 0.289 | 0.282 | 0.277 | 0.271 | 0.266 | 0.262 | 0.258 | 0.254 | 0.251 |
| 1.00 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table 5. Superheat correction factor $K_{SH}$**

For derivation of these factors see appendix A.

| Pressure (in bar absolute) | Saturation temperature (in °C) | Inlet temperature (in °C) | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 220 | 230 | 240 | 250 | 260 | 270 | 280 | 290 | 300 | 310 | 320 | 330 | 340 | 350 | 360 | 370 | 380 | 390 |
| 2 | 120 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 | 0.83 | 0.83 |
| 3 | 133 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 | 0.84 | 0.83 |
| 4 | 144 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 | 0.84 | 0.83 |
| 5 | 152 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.90 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 | 0.85 | 0.84 | 0.84 | 0.83 |
| 6 | 159 | | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 | 0.85 | 0.84 | 0.84 | 0.83 |
| 7 | 165 | | | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.90 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 | 0.85 | 0.84 | 0.84 | 0.83 |
| 8 | 170 | | | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 | 0.83 |
| 9 | 175 | | | | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 | 0.83 |
| 10 | 180 | | | | 1.00 | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 | 0.83 |
| 11 | 184 | | | | | 1.00 | 1.00 | 0.99 | 0.99 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.90 | 0.89 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 | 0.83 |
| 12 | 188 | | | | | 1.00 | 1.00 | 0.99 | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.92 | 0.90 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 | 0.83 |
| 13 | 192 | | | | | | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.93 | 0.92 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 | 0.83 |
| 14 | 195 | | | | | | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 | 0.83 |
| 15 | 198 | | | | | | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 | 0.84 |
| 16 | 201 | | | | | | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.84 |
| 17 | 204 | | | | | | | 1.00 | 0.99 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.84 |
| 18 | 207 | | | | | | | 1.00 | 1.00 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.84 |
| 19 | 210 | | | | | | | 1.00 | 1.00 | 0.99 | 0.98 | 0.97 | 0.95 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 |
| 20 | 212 | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 |
| 21 | 215 | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 |
| 22 | 217 | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 |
| 23 | 220 | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 |
| 24 | 222 | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 | 0.85 | 0.84 |
| 26 | 226 | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 | 0.85 | 0.84 |
| 28 | 230 | | | | | | | | | 1.00 | 0.99 | 0.99 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 | 0.85 | 0.84 |
| 30 | 234 | | | | | | | | | | 0.99 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.91 | 0.90 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 |
| 32 | 237 | | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 |
| 34 | 241 | | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.95 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 |
| 36 | 244 | | | | | | | | | | | 1.00 | 0.98 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.90 | 0.88 | 0.87 | 0.86 | 0.86 | 0.84 |
| 38 | 247 | | | | | | | | | | | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.94 | 0.93 | 0.91 | 0.90 | 0.90 | 0.88 | 0.87 | 0.87 | 0.86 | 0.85 |
| 40 | 250 | | | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.90 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 |
| 42 | 253 | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 |
| 44 | 256 | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 |
| 46 | 259 | | | | | | | | | | | | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.85 |
| 48 | 261 | | | | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 | 0.86 |
| 50 | 264 | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.91 | 0.89 | 0.88 | 0.87 | 0.87 | 0.86 |
| 52 | 266 | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.88 | 0.88 | 0.87 | 0.86 |
| 54 | 269 | | | | | | | | | | | | | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 |
| 56 | 271 | | | | | | | | | | | | | 1.00 | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 |
| 58 | 273 | | | | | | | | | | | | | | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 |
| 60 | 276 | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.93 | 0.92 | 0.90 | 0.89 | 0.88 | 0.87 | 0.86 |
| 62 | 278 | | | | | | | | | | | | | | 0.99 | 0.99 | 0.97 | 0.96 | 0.94 | 0.93 | 0.92 | 0.91 | 0.90 | 0.88 | 0.88 | 0.87 |
| 64 | 280 | | | | | | | | | | | | | | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 |
| 66 | 282 | | | | | | | | | | | | | | | 0.99 | 0.97 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 |
| 68 | 284 | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.96 | 0.95 | 0.94 | 0.93 | 0.91 | 0.90 | 0.89 | 0.88 | 0.87 |
| 70 | 286 | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.95 | 0.94 | 0.94 | 0.92 | 0.90 | 0.89 | 0.88 | 0.87 |
| 75 | 290 | | | | | | | | | | | | | | | 1.00 | 0.99 | 0.97 | 0.96 | 0.95 | 0.94 | 0.92 | 0.91 | 0.90 | 0.89 | 0.88 |
| 80 | 295 | | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.96 | 0.96 | 0.94 | 0.93 | 0.91 | 0.91 | 0.89 | 0.88 |
| 85 | 299 | | | | | | | | | | | | | | | | 1.00 | 0.98 | 0.97 | 0.96 | 0.95 | 0.93 | 0.92 | 0.91 | 0.90 | 0.88 |
| 90 | 303 | | | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.93 | 0.91 | 0.90 | 0.89 |
| 95 | 307 | | | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.97 | 0.95 | 0.93 | 0.92 | 0.90 | 0.89 |
| 100 | 311 | | | | | | | | | | | | | | | | | 1.00 | 0.99 | 0.97 | 0.97 | 0.96 | 0.94 | 0.92 | 0.91 | 0.90 |
| 105 | 314 | | | | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.97 | 0.95 | 0.93 | 0.92 | 0.90 |
| 110 | 318 | | | | | | | | | | | | | | | | | | 1.00 | 0.98 | 0.98 | 0.97 | 0.95 | 0.94 | 0.92 | 0.91 |
| 115 | 321 | | | | | | | | | | | | | | | | | | 1.00 | 0.98 | 0.98 | 0.97 | 0.96 | 0.94 | 0.92 | 0.91 |
| 120 | 324 | | | | | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.96 | 0.94 | 0.92 | 0.91 |
| 125 | 327 | | | | | | | | | | | | | | | | | | | 0.99 | 0.98 | 0.97 | 0.97 | 0.95 | 0.93 | 0.91 |
| 130 | 331 | | | | | | | | | | | | | | | | | | | 1.00 | 0.98 | 0.97 | 0.97 | 0.95 | 0.93 | 0.91 |
| 135 | 333 | | | | | | | | | | | | | | | | | | | | 0.99 | 0.97 | 0.96 | 0.95 | 0.93 | 0.91 |
| 140 | 336 | | | | | | | | | | | | | | | | | | | | 0.99 | 0.97 | 0.96 | 0.96 | 0.93 | 0.91 |
| 145 | 339 | | | | | | | | | | | | | | | | | | | | 1.00 | 0.98 | 0.96 | 0.96 | 0.94 | 0.92 |
| 150 | 342 | | | | | | | | | | | | | | | | | | | | 1.00 | 0.98 | 0.96 | 0.96 | 0.94 | 0.92 |
| 155 | 344 | | | | | | | | | | | | | | | | | | | | | 0.99 | 0.97 | 0.96 | 0.94 | 0.92 |
| 160 | 347 | | | | | | | | | | | | | | | | | | | | | 1.00 | 0.97 | 0.95 | 0.95 | 0.92 |
| 165 | 350 | | | | | | | | | | | | | | | | | | | | | | 0.97 | 0.95 | 0.95 | 0.92 |
| 170 | 352 | | | | | | | | | | | | | | | | | | | | | | | 0.95 | 0.95 | 0.92 |
| 175 | 354 | | | | | | | | | | | | | | | | | | | | | | 0.98 | 0.95 | 0.94 | 0.93 |
| 180 | 357 | | | | | | | | | | | | | | | | | | | | | | 0.99 | 0.95 | 0.94 | 0.93 |
| 185 | 359 | | | | | | | | | | | | | | | | | | | | | | 1.00 | 0.96 | 0.94 | 0.93 |
| 190 | 361 | | | | | | | | | | | | | | | | | | | | | | 1.00 | 0.96 | 0.94 | 0.93 |
| 195 | 364 | | | | | | | | | | | | | | | | | | | | | | | 0.96 | 0.94 | 0.92 |
| 200 | 366 | | | | | | | | | | | | | | | | | | | | | | | 0.97 | 0.93 | 0.92 |
| 205 | 368 | | | | | | | | | | | | | | | | | | | | | | | 0.98 | 0.93 | 0.92 |
| 210 | 370 | | | | | | | | | | | | | | | | | | | | | | | | 0.93 | 0.91 |
| 215 | 372 | | | | | | | | | | | | | | | | | | | | | | | | 0.94 | 0.91 |
| 220 | 374 | | | | | | | | | | | | | | | | | | | | | | | | 0.94 | 0.90 |

| Inlet temperature (in °C) | | | | | | | | | | | | | | | | | | | | | | | | | Saturation temperature (in °C) | Pressure (in bar absolute) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 410 | 420 | 430 | 440 | 450 | 460 | 470 | 480 | 490 | 500 | 510 | 520 | 530 | 540 | 550 | 560 | 570 | 580 | 590 | 600 | 610 | 620 | 630 | 640 | | |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 120 | 2 |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 133 | 3 |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 144 | 4 |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 152 | 5 |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 159 | 6 |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 165 | 7 |
| 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 170 | 8 |
| 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 175 | 9 |
| 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 180 | 10 |
| 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 184 | 11 |
| 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 188 | 12 |
| 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 192 | 13 |
| 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 195 | 14 |
| 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 198 | 15 |
| 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 201 | 16 |
| 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 0.70 | 204 | 17 |
| 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 207 | 18 |
| 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 210 | 19 |
| 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 212 | 20 |
| 0.83 | 0.82 | 0.82 | 0.82 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 215 | 21 |
| 0.83 | 0.83 | 0.82 | 0.82 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 217 | 22 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 220 | 23 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 222 | 24 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 226 | 26 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 230 | 28 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 234 | 30 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.79 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 237 | 32 |
| 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 241 | 34 |
| 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 244 | 36 |
| 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 247 | 38 |
| 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 250 | 40 |
| 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.71 | 253 | 42 |
| 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 256 | 44 |
| 0.85 | 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.71 | 259 | 46 |
| 0.85 | 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 261 | 48 |
| 0.85 | 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 264 | 50 |
| 0.85 | 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 266 | 52 |
| 0.85 | 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 269 | 54 |
| 0.85 | 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 271 | 56 |
| 0.85 | 0.85 | 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 273 | 58 |
| 0.85 | 0.85 | 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 276 | 60 |
| 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 278 | 62 |
| 0.86 | 0.85 | 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 280 | 64 |
| 0.86 | 0.85 | 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 282 | 66 |
| 0.86 | 0.85 | 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 284 | 68 |
| 0.86 | 0.85 | 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 286 | 70 |
| 0.87 | 0.85 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 290 | 75 |
| 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 295 | 80 |
| 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 299 | 85 |
| 0.88 | 0.87 | 0.86 | 0.84 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 303 | 90 |
| 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.75 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 307 | 95 |
| 0.88 | 0.87 | 0.86 | 0.85 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.71 | 311 | 100 |
| 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 314 | 105 |
| 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.75 | 0.74 | 0.73 | 0.72 | 0.72 | 0.72 | 318 | 110 |
| 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.75 | 0.74 | 0.73 | 0.72 | 0.72 | 0.71 | 321 | 115 |
| 0.89 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 324 | 120 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.71 | 0.71 | 327 | 125 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.79 | 0.79 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 331 | 130 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.74 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 333 | 135 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.85 | 0.83 | 0.82 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 336 | 140 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 339 | 145 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.75 | 0.75 | 0.74 | 0.73 | 0.73 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 342 | 150 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.77 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.73 | 0.73 | 0.71 | 0.71 | 0.70 | 0.70 | 0.69 | 344 | 155 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 | 0.70 | 0.70 | 0.69 | 0.69 | 347 | 160 |
| 0.90 | 0.88 | 0.87 | 0.86 | 0.84 | 0.83 | 0.82 | 0.80 | 0.79 | 0.78 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.72 | 0.72 | 0.71 | 0.70 | 0.70 | 0.69 | 0.68 | 350 | 165 |
| 0.90 | 0.88 | 0.86 | 0.86 | 0.84 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 0.69 | 0.69 | 0.68 | 352 | 170 |
| 0.90 | 0.88 | 0.86 | 0.86 | 0.83 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.72 | 0.71 | 0.71 | 0.70 | 0.69 | 0.69 | 0.68 | 0.68 | 354 | 175 |
| 0.90 | 0.88 | 0.86 | 0.86 | 0.83 | 0.82 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.76 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.71 | 0.71 | 0.71 | 0.69 | 0.69 | 0.68 | 0.68 | 0.67 | 357 | 180 |
| 0.90 | 0.88 | 0.86 | 0.85 | 0.83 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 0.70 | 0.69 | 0.68 | 0.68 | 0.67 | 0.67 | 359 | 185 |
| 0.90 | 0.88 | 0.86 | 0.84 | 0.82 | 0.81 | 0.80 | 0.79 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 | 0.73 | 0.73 | 0.72 | 0.71 | 0.70 | 0.70 | 0.70 | 0.68 | 0.68 | 0.67 | 0.67 | 0.66 | 361 | 190 |
| 0.90 | 0.87 | 0.85 | 0.83 | 0.82 | 0.80 | 0.79 | 0.79 | 0.77 | 0.76 | 0.75 | 0.74 | 0.73 | 0.72 | 0.72 | 0.71 | 0.70 | 0.70 | 0.69 | 0.69 | 0.68 | 0.67 | 0.67 | 0.66 | 0.65 | 364 | 195 |
| 0.90 | 0.87 | 0.85 | 0.83 | 0.81 | 0.80 | 0.79 | 0.78 | 0.76 | 0.75 | 0.74 | 0.74 | 0.73 | 0.72 | 0.72 | 0.70 | 0.70 | 0.69 | 0.68 | 0.68 | 0.67 | 0.67 | 0.66 | 0.65 | 0.65 | 366 | 200 |
| 0.90 | 0.87 | 0.85 | 0.83 | 0.81 | 0.79 | 0.78 | 0.77 | 0.76 | 0.75 | 0.74 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 0.69 | 0.68 | 0.68 | 0.68 | 0.66 | 0.66 | 0.66 | 0.65 | 0.64 | 368 | 205 |
| 0.90 | 0.87 | 0.84 | 0.82 | 0.80 | 0.79 | 0.78 | 0.76 | 0.75 | 0.74 | 0.73 | 0.72 | 0.71 | 0.70 | 0.70 | 0.69 | 0.68 | 0.68 | 0.67 | 0.67 | 0.66 | 0.65 | 0.65 | 0.64 | 0.64 | 370 | 210 |
| 0.89 | 0.86 | 0.84 | 0.82 | 0.80 | 0.78 | 0.77 | 0.76 | 0.74 | 0.73 | 0.72 | 0.71 | 0.71 | 0.70 | 0.69 | 0.68 | 0.67 | 0.67 | 0.66 | 0.66 | 0.65 | 0.64 | 0.64 | 0.63 | 0.63 | 372 | 215 |
| 0.89 | 0.86 | 0.83 | 0.81 | 0.79 | 0.78 | 0.76 | 0.75 | 0.74 | 0.73 | 0.72 | 0.71 | 0.70 | 0.69 | 0.68 | 0.67 | 0.67 | 0.66 | 0.65 | 0.65 | 0.64 | 0.64 | 0.63 | 0.62 | 0.62 | 374 | 220 |

*blank*

## Section seven. Safety valves for boilers, superheaters, reheaters and economizers

### 22. Boilers and superheaters

In no case shall a steam boiler with an evaporation rate of more than 3700 kg/h or a hot water boiler with a rating of more than 2350 kW be fitted with less than two single safety valves or one double safety valve. At least one safety valve shall be fitted on the outlet side of the superheater, where fitted, and can be considered a part of the safety valve complement of the boiler provided that there is no intervening stop valve between the boiler and the superheater.

The discharge capacity, $p$, of any safety valve on the superheater or boiler shall be calculated in accordance with **21.5.2** and **21.5.4** from the equation:

$$p = 1.1p' + 1$$

where $p'$ is the highest set pressure (in bar gauge) of the boiler safety valves.

NOTE. $p'$ should not exceed the boiler design pressure.

The total capacity of the superheater valve(s) so calculated shall be not less than 20 % of the evaporative capacity of the boiler.

### 23. Reheaters and superheaters separated from the boiler

Reheaters, and superheaters separated from the boiler by an intervening stop valve, shall be fitted with appropriate safety valves. These safety valves shall not be considered as part of the safety valve complement of the boiler.

### 24. Safety valves for economizers

Economizers, except those directly connected to the boiler without an intervening stop valve, shall be fitted with at least one safety valve. Whenever practicable, only safety valves of inlet size DN 50 shall be used. The set pressure shall not exceed the maximum permissible working pressure of the economizer.

### 25. Operational margins

To prevent the unnecessary lifting of the safety valves there shall be an adequate margin between the actual pressure at which the boiler generates and delivers steam and the lowest pressure at which any of the safety valves are set to lift.

## Appendix A

### Derivation of superheat correction factors

**A.1** The superheat correction factor, $K_{Sh}$, (see table 5) is the ratio of the maximum isentropic nozzle flow, $Q_{mSh}$, for a given superheat inlet condition to the Napier flow, $Q_m$, for the dry saturated condition at the same inlet pressure, i.e.:

$$K_{Sh} = \frac{Q_{mSh}}{Q_m}$$

**A.2** Determination of the maximum isentropic flow at superheat conditions, $Q_{mSh}$, is by iteration of successive isentropic unit area flows until convergence to maximum unit flow, $q_{mShmax}$, occurs. $q_{mSh}$ (in kg/s/m$^2$) is given by the equation

$$q_{mSh} = \frac{V}{v}$$

where

$v$ is the throat specific volume (in m$^3$/kg);

$V$ is the throat velocity of an ideal converging nozzle (in m/s) = $2(h - h_t)$;

$h$ is the inlet enthalpy (in J/kg);

$h_t$ is the throat enthalpy (in J/kg).

## Appendix B

### Guidance on safety valve mounting

**B.1** Excessive pressure loss at the inlet of a safety valve will cause extremely rapid opening and closing of the valve, which is known as 'chattering' or 'hammering'. This may result in reduced capacity, damage to seating faces and other parts of the valve.

The adoption of the following recommendations will reduce or eliminate these factors.

(a) Safety valves should be installed at least 8 to 10 pipe diameters downstream from any converging or diverging 'Y' fitting or any bend in a steam line. This distance should be increased if the direction of change of the steam flow is from vertically upwards to horizontal in such a manner as to increase the density of the flow in the area directly beneath the safety valve nozzle.

(b) A safety valve branch should never be installed in a steam line in a position directly opposite a branch on the lower side of the steam line.

(c) Inlet branches should have:

(1) corners radiused to not less than one-quarter of the bore, or

(2) a taper bore with an inlet area approximately twice that of the outlet, or

(3) the branch entrance rounded at the downstream corner to a radius of not less than one-quarter of the bore. This radius should be reduced gradually, leaving only a small portion of the upstream corner sharp.

**B.2** Excessive steam line vibrations are known to produce inconsistencies in safety valve set pressures and induce chatter.

**B.3** All associated discharge pipework should be installed in such a way that it will not impose undue stresses on the safety valve which could result in distortion and leakage at pressures below the set point.

Discharge piping should not be supported by the valve. The maximum mass on the outlet of the valve should not exceed the mass of the valve exhaust pipe, i.e. flange elbow and short pipe and drip pan, where fitted. The distance from the discharge piping centreline to the centreline of the valve should be kept to a minimum.

Clearances between the valve exhaust piping and the discharge piping should be sufficient to avoid any additional forces being applied to the valve due to thermal expansion of the boiler and discharge piping and/or discharge piping vibration.

NOTE. Particular attention is drawn to the requirements of BS 806 where bellows or flexible hoses are incorporated in safety valve discharge piping.

**B.4** For each safety valve fitted with discharge piping an individual unrestricted drain is necessary having a continuous fall to a place where the discharge cannot injure any person.

**B.5** The design of the discharge piping should be such as to limit to 12 % of the set pressure, with a maximum of 17 bar, the built-up back pressure as calculated at the safety valve outlet connection, when the valve is discharging the certified discharge capacity. If the calculated back pressure is greater than that specified above, this should only be accepted with the agreement of the safety valve manufacturer.

## Appendix C

### Inspection and testing facilities

**C.1 Inspection facilities.** The purchaser or his representative shall have access, at all reasonable times to those portions of the manufacturer's works in which the production is being carried out and in which the testing is taking place.

**C.2 Testing facilities.** The manufacturer shall provide labour and appliances for such testing as may be carried out on his premises in accordance with this standard. Failing facilities at his own works for making the prescribed tests, the manufacturer shall make arrangements for carrying out the tests elsewhere.

## Publications referred to

BS 21 Pipe threads for tubes and fittings where pressure-tight joints are made on the threads
BS 759* Valves, gauges and other safety fittings for application to boilers and to piping installations for and in connection with boilers
Part 1 Specification for valves, mountings and fittings
Part 2 Specification for safety valves (obsolescent)
BS 779 Cast iron boilers for central heating and indirect hot water supply (44 kW rating and above)
BS 806 Ferrous piping systems for and in connection with land boilers
BS 855 Specification for welded steel boilers for central heating and indirect hot water supply (rated output 44 kW to 3 MW)
BS 970 Wrough steels in the form of blooms, billets, bars and forgings
Part 1 Carbon and carbon manganese steels including free cutting steels
Part 5 Carbon and alloy spring steels for the manufacture of hot-formed springs
BS 1113 Water-tube steam generating plant (including super-heaters, reheaters and steel tube economizers)
BS 1400 Copper alloy ingots and copper alloy castings
BS 1452 Specification for grey iron castings
BS 1503 Specification for steel forgings (including semi-finished forged products) for pressure purposes
BS 1504 Specification for steel castings for pressure purposes
BS 1560 Steel pipe flanges and flanged fittings (nominal sizes ½ in to 24 in) for the petroleum industry
Part 2 Metric dimensions
BS 1726 Guide to the design and specification of coil springs
Part 1 Helical compression springs
BS 1768 Unified precision hexagon bolts, screws and nuts (UNC and UNF threads). Normal series
BS 1769 Unified black hexagon bolts, screws and nuts (UNC and UNF threads). Heavy series
BS 2056 Rust, acid and heat resisting steel wire for springs
BS 2633 Class 1 arc welding of ferritic steel pipework for carrying fluids
BS 2693 Screwed studs
Part 1 General purpose studs
BS 2708 Unified black square and hexagon bolts, screws and nuts (UNC and UNF threads). Normal series
BS 2790 Specification for shell boilers of welded construction
BS 2803 Prehardened and tempered carbon and low alloy round steel wire for springs for general engineering purposes
BS 3692 ISO metric precision hexagon bolts, screws and nuts
BS 4080 Methods for non-destructive testing of steel castings
BS 4190 ISO metric black hexagon bolts, screws and nuts
BS 4439 Screwed studs for general purposes
BS 4504 Flanges and bolting for pipes, valves and fittings. Metric series
BS 4570 Fusion welding of steel castings
Part 1 Production, rectification and repair
BS 4882 Bolting for flanges and pressure containing purposes
BS 5216 Patented cold drawn carbon steel wire for mechanical springs
BS 5500 Unfired fusion welded pressure vessels

ISO 4126* Safety valves, general requirements

* Referred to in the foreword only.

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Liquefied Petroleum Gas Industry Technical Association (UK)
Process Plant Association
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