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**Industrial-process control valves –
Part 2-3: Flow capacity – Test procedures**

**Vannes de régulation des processus industriels –
Partie 2-3: Capacité d'écoulement – Procédures d'essai**



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INTERNATIONAL
ELECTROTECHNICAL
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INTERNATIONALE

ICS 23.060.40; 25.040.40

ISBN 978-2-8322-8666-1

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INDUSTRIAL-PROCESS CONTROL VALVES –

Part 2-3: Flow capacity – Test procedures

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International Standard IEC 60534-2-3 has been prepared by subcommittee 65B: Measurement and control devices, of IEC technical committee 65: Industrial-process measurement, control and automation.

The third edition cancels and replaces the second edition published in 1997, of which it constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Addition of informative Annexes B, C, D, E and F.
- b) Organizational and formatting changes were made to group technically related subject matter.

The text of this standard is based on the following documents:

FDIS	Report on voting
65B/1025/FDIS	65B/1028/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 60534 series, published under the general title *Industrial-process control valves*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

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INDUSTRIAL-PROCESS CONTROL VALVES –

Part 2-3: Flow capacity – Test procedures

1 Scope

This part of IEC 60534 is applicable to industrial-process control valves and provides the flow capacity test procedures for determining the following variables used in the equations given in IEC 60534-2-1:

- a) flow coefficient C ;
- b) liquid pressure recovery factor without attached fittings F_L ;
- c) combined liquid pressure recovery factor and piping geometry factor of a control valve with attached fittings F_{LP} ;
- d) piping geometry factor F_P ;
- e) pressure differential ratio factors x_T and x_{TP} ;
- f) valve style modifier F_d ;
- g) Reynolds number factor F_R .

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60534-1, *Industrial-process control valves – Part 1: Control valve terminology and general considerations*

IEC 60534-2-1:2011, *Industrial-process control valves – Part 2-1: Flow capacity – Sizing equations for fluid flow under installed conditions*

IEC 60534-8-2, *Industrial-process control valves – Part 8-2: Noise considerations – Laboratory measurement of noise generated by hydrodynamic flow through control valves*

IEC 61298-1, *Process measurement and control devices – General methods and procedures for evaluating performance – Part 1: General considerations*

IEC 61298-2, *Process measurement and control devices – General methods and procedures for evaluating performance – Part 2: Tests under reference conditions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60534-1, IEC 60534-2-1, IEC 61298-1, and IEC 61298-2 apply.

4 Symbols

Symbol	Description	Unit
C	Flow coefficient (K_v , C_v)	Various (see IEC 60534-1)
C_R	Flow coefficient at rated travel	Various (see IEC 60534-1)
d	Nominal valve size (DN)	mm
F_d	Valve style modifier	1
F_F	Liquid critical pressure ratio factor	1
F_L	Liquid pressure recovery factor of a control valve without attached fittings	1
F_{LP}	Combined liquid pressure recovery factor and piping geometry factor of a control valve with attached fittings	1
F_P	Piping geometry factor	1
F_R	Reynolds number factor	1
F_γ	Specific heat ratio factor	1
M	Molecular mass of flowing fluid	kg/kmol
N	Numerical constants (see Table 3)	Various (see Note 1)
p_c	Thermodynamic critical pressure	kPa or bar (see Note 2)
p_v	Vapour pressure of liquid at inlet temperature	kPa or bar
p_1	Inlet absolute static pressure measured at the upstream pressure tap	kPa or bar
p_2	Outlet absolute static pressure measured at the downstream pressure tap	kPa or bar
Δp	Differential pressure ($p_1 - p_2$) between upstream and downstream pressure taps	kPa or bar
$\Delta p_{\max}$	Maximum pressure differential	kPa or bar
$\Delta p_{\max(L)}$	Maximum effective Δp without attached fittings	kPa or bar
$\Delta p_{\max(LP)}$	Maximum effective Δp with attached fittings	kPa or bar
Q	Volumetric flow rate	m ³ /h (see Note 3)
$Q_{\max}$	Maximum volumetric flow rate (choked flow conditions)	m ³ /h
$Q_{\max(L)}$	Maximum volumetric flow rate for incompressible fluids (choked flow conditions without attached fittings)	m ³ /h
$Q_{\max(LP)}$	Maximum volumetric flow rate for incompressible fluids (choked flow conditions with attached fittings)	m ³ /h
$Q_{\max(T)}$	Maximum volumetric flow rate for compressible fluids (choked flow conditions without attached fittings)	m ³ /h
$Q_{\max(TP)}$	Maximum volumetric flow rate for compressible fluids (choked flow conditions with attached fittings)	m ³ /h
Re_v	Valve Reynolds number	1
T_1	Inlet absolute temperature	K
t_s	Reference temperature for standard conditions	°C
X	Ratio of pressure differential to inlet absolute pressure ($\Delta p/p_1$)	1
x_T	Pressure differential ratio factor of a control valve without attached fittings for choked flow	1
x_{TP}	Pressure differential ratio factor of a control valve with attached fittings for choked flow	1
Y	Expansion factor	1
Z	Compressibility factor ($Z = 1$ for gases that exhibit ideal gas behaviour)	1
γ	Specific heat ratio	1
ν	Kinematic viscosity	m ² /s (see Note 4)
ζ	Velocity head loss coefficient of a reducer, expander or other fitting attached to a control valve	1
ρ_1/ρ_o	Relative density ($\rho_1/\rho_o = 1$ for water at 15 °C)	1

NOTE 1 To determine the units for the numerical constants, dimensional analysis may be performed on the appropriate equations using the units given in Table 1.

NOTE 2 $1 \text{ bar} = 10^2 \text{ kPa} = 10^5 \text{ Pa}$.

NOTE 3 Compressible fluid volumetric flow rates in m^3/h , identified by the symbol Q , refer to standard conditions which are an absolute pressure of 101,325 kPa (1,013 25 bar) and a temperature of either 0 °C or 15 °C (see Table 3).

NOTE 4 1 centistoke = $10^{-6} \text{ m}^2/\text{s}$.

5 Test system

5.1 Test specimen

The test specimen is any valve or combination of valve, pipe reducer, and expander or other devices attached to the valve body for which test data are required. See Annex A for additional examples of test specimens representative of typical field installations.

Additional considerations apply when testing certain styles of high-capacity control valves, e.g., ball or butterfly valves. These valves may produce free jets in the downstream test section impacting the location of the pressure recovery zone. See Clause 6 for expected accuracies.

Fractional C valves (valves where $C \ll N_{18}$) are addressed in 8.1.2.

Physical or computer-based modelling of control valves as the basis for flow coefficient determination is permissible but is outside the scope of this standard. When modelling, it is incumbent on the practitioner to employ suitable modelling techniques to validate the model and scaling relationships to actual flow data, and to document the nature of the model.

5.2 Test section

A basic flow test system is shown in Figure 1.

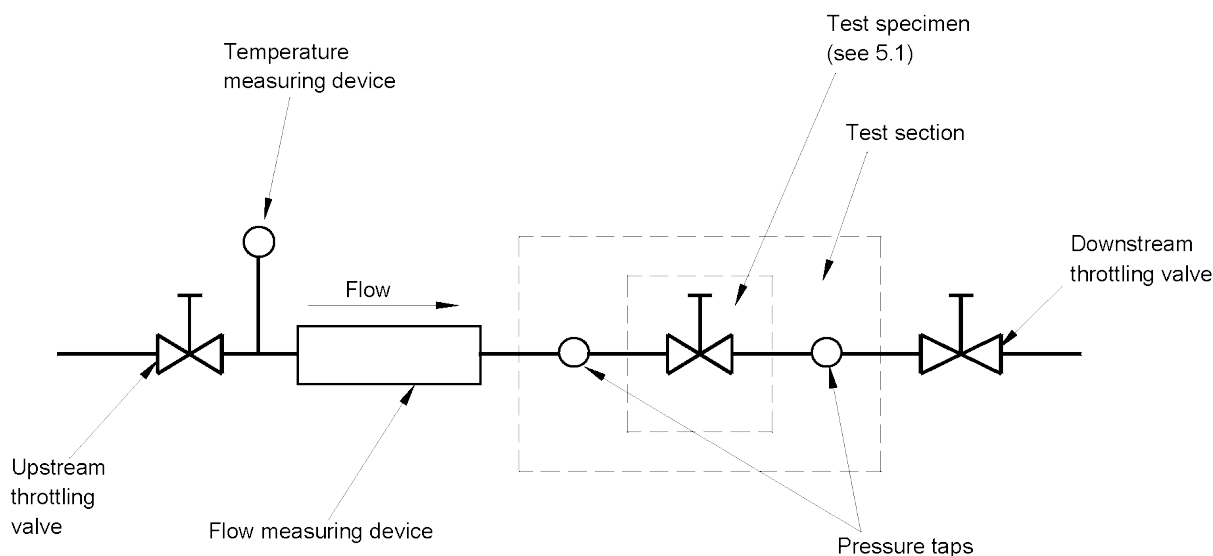


Figure 1 – Basic flow test system

The upstream and downstream piping adjacent to the test specimen should conform to the nominal size of the test specimen connection and to the straight length requirements of Figure 2. The inlet and outlet piping shall be suitable for the maximum respective pressures that can be applied by the test system (Table B.3 provides data for commonly used pipe).

The inside diameter (ID) of the pipe normally should be within $\pm 2\%$ of the actual inside diameter of the inlet and outlet of the test specimen for all valve sizes. As the C/d^2 ratio (of the test valve) increases, the mismatch in diameters becomes more problematic. Potential pressure losses associated with the inlet and outlet joints become significant in comparison to the loss associated the valve. Also, a significant discontinuity at the valve outlet could affect the downstream (p_2) pressure measurement. One indication of the significance of mismatched diameters is the value of the piping geometry factor (F_p) based on the internal diameters. This value approaches unity for a standard test, i.e., for equal line and specimen inside diameters. Therefore, to ensure the proper accuracy for the test, it shall be demonstrated by either calculation or test that $0,99 \leq F_p \leq 1,01$. If $F_p < 0,99$, or $F_p > 1,01$ it shall be so noted in the test data (see 8.1.5 or 10.1.5). See Annex F for a sample calculation.

The inside surfaces shall be reasonably free of flaking rust or mill scale and without irregularities that could cause excessive fluid frictional losses.

5.3 Throttling valves

The upstream and downstream throttling valves are used to control the pressure differential across the test section pressure taps and to maintain a specific upstream or downstream pressure. There are no restrictions as to style of these valves. However, the downstream valve should be of sufficient capacity, and may be larger than the nominal size of the test specimen, to ensure that choked flow can be achieved at the test specimen for both compressible and incompressible flow. Vaporization at the upstream throttling valve shall be avoided when testing with liquids.

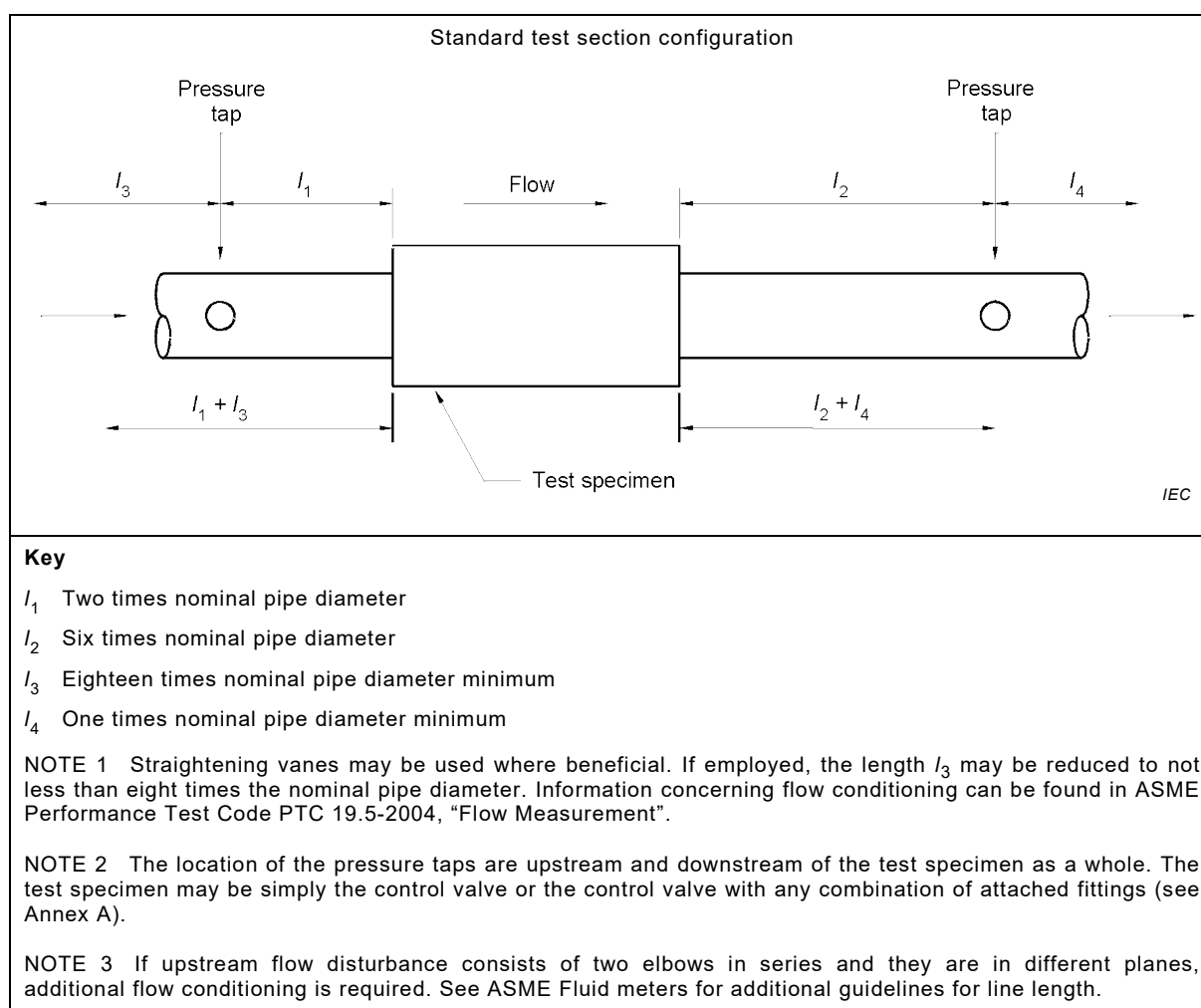


Figure 2 – Test section piping requirements

5.4 Flow measurement

The flow measuring instrument may be located upstream or downstream of the test section, and may be any device which meets the specified accuracy. The accuracy rating of the instrument shall be $\pm 2\%$ of actual output reading. The resolution and repeatability of the instrument shall be within $\pm 0,5\%$. The measuring instrument shall be calibrated as frequently as necessary to maintain specified accuracy. All guidelines specific to the flow-measuring instrument regarding flow conditioning (e.g., the number of straight pipe diameters, upstream and downstream of the instrument, etc.) shall be followed.

5.5 Pressure taps

Pressure taps shall be provided on the test section piping in accordance with the requirements listed in Figure 3. These pressure taps shall conform to the construction illustrated in Figure 3. The edge of the pressure tap hole shall be clean and sharp (i.e., check for corrosion and/or erosion) or slightly rounded, free from burrs, wire edges or other irregularities. In no case shall any fitting protrude inside the pipe.

Orientation:

Incompressible fluids – Tap centrelines should be located horizontally to reduce the possibility of air entrapment or dirt collection in the pressure taps.

Compressible fluids – Tap centrelines should be oriented horizontally or vertically above pipe to reduce the possibility of dirt or condensate entrapment.

For butterfly and other rotary valves, the pressure taps shall be aligned (parallel) to the main shaft of the valve to reduce the effect of the velocity head of the flowing fluid on the pressure measurement.

Multiple pressure taps can be used on each test section for averaging pressure measurements. Each tap shall conform to the requirements in Figure 3.

See 5.9 for other installation guidelines.

5.6 Pressure measurement

All pressure and pressure differential measurements shall be made using instruments with an accuracy rating of $\pm 2\%$ of actual output reading. Pressure-measuring devices shall be calibrated as frequently as necessary to maintain specified accuracy.

If individual pressure measurements (p_1 , p_2) are used in lieu of a single differential pressure measurement (Δp), care shall be taken to select instruments which are accurate enough that the calculated pressure differential value ($p_1 - p_2$) is known with an accuracy at least as good as the accuracy rating stated above for pressure differential measurements.

5.7 Temperature measurement

The fluid temperature shall be measured using an instrument with an accuracy rating of $\pm 1\text{ }^\circ\text{C}$ ($\pm 2\text{ }^\circ\text{F}$) of actual output reading. The temperature measuring probe should be chosen and positioned to have minimum effect on the flow and pressure measurements. Thermocouples used for temperature measurement should be at least Class B according to IEC 60751.

The inlet fluid temperature shall remain constant within $\pm 3\text{ }^\circ\text{C}$ ($\pm 5\text{ }^\circ\text{F}$) over the time interval during which the test data is recorded for each specific test point. The flowing system should be allowed to stabilize for a period of time that exceeds the time constant of the measuring device to ensure that the correct temperature is being recorded.

5.8 Valve travel

The valve travel shall be fixed within $\pm 0,5\%$ of the rated travel during any one specific flow test.

The accuracy rating of the travel-measuring instrument shall be $\pm 0,2\%$ of rated travel.

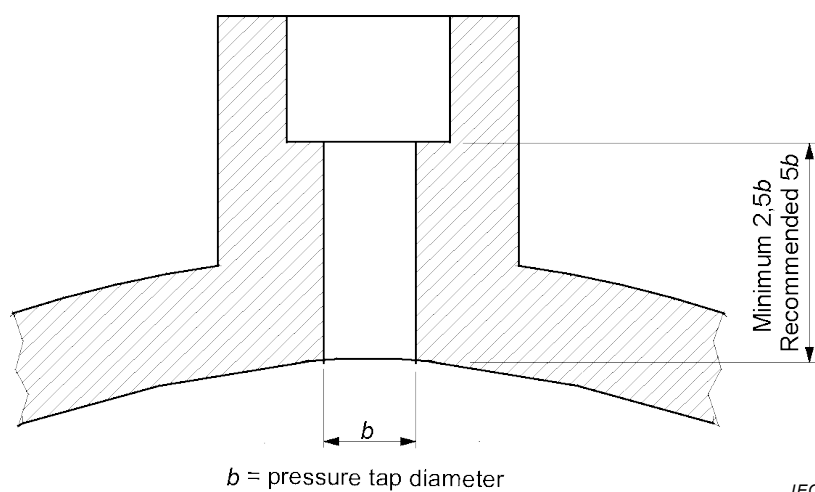
5.9 Installation of test specimen

Alignment between the centreline of the test section piping and the centreline of the inlet and outlet of the test specimen shall be within (see Table 1 and Figure 3):

Table 1 – Test specimen alignment

Pipe size	Allowable misalignment
DN 15 through DN 25	0,8 mm
DN 32 through DN 150	1,6 mm
DN 200 and larger	0,01 nominal pipe diameter

The inside diameter of each gasket shall be sized and the gasket positioned so that it does not protrude inside the pipe.



NOTE 1 Any suitable method of making the physical connection is acceptable if above recommendations are adhered to.

NOTE 2 Reference: ASME Performance Test Code PTC 19.5-1972, "Applications. Part II of Fluid Meters, Interim Supplement on Instruments and Apparatus."

Size of pipe	" b " Not exceeding	" b " Not less than
Less than 50 mm	6 mm	3 mm
50 mm to 75 mm	9 mm	3 mm
100 mm to 200 mm	13 mm	3 mm
250 mm and greater	19 mm	3 mm

Figure 3 – Recommended pressure tap connection

6 Accuracy of tests

Valves having an $\frac{C}{N_{18}d^2} < 0,047$ and $x_T < 0,84$ at tested travel will have a calculated flow coefficient, C , of the test specimen within a tolerance of $\pm 5\%$. The tolerance for valves that do not meet these criteria may exceed 5% . These accuracy statements apply when fully turbulent flow can be established. See Annex D for further information when this is not the case.

See cautions presented in 5.1.

7 Test fluids

7.1 Incompressible fluids

Fresh water that is free of appreciable entrained solids (i.e., $< 1\,000 \times 10^{-6}$ dissolved salts; $< 1\,000 \times 10^{-6}$ entrained solids) shall be the basic fluid used in this procedure. Inhibitors may be used to prevent or retard corrosion and to prevent the growth of organic matter. The aggregate effect of additives and all contaminants on density or viscosity shall be evaluated by computation using the equations in this standard. The sizing coefficient shall not be affected by more than $0,1\%$. Test fluids other than fresh water may be required for obtaining F_R and F_F . Test fluid temperature range for fresh water should be $5\text{ }^\circ\text{C}$ to $40\text{ }^\circ\text{C}$.

7.2 Compressible fluids

Air or some other compressible fluid shall be used as the basic fluid in this test procedure. The test fluid shall fall in the ideal gas behaviour range under test conditions, and therefore shall have a ratio of specific heats that falls in the range $1,2 \leq \gamma \leq 1,6$ (see Cunningham, Driskell, in the Bibliography). Vapours that may approach their condensation points at the vena contracta of the specimen are not acceptable as test fluids. Care should be taken to avoid internal icing during the test.

8 Test procedure for incompressible fluids

8.1 Test procedure for flow coefficient C

8.1.1 Install the test specimen without attached fittings in accordance with piping requirements in Figure 2.

8.1.2 Flow tests shall include flow measurements at three widely spaced pressure differentials (but not less than $0,1$ bar) within the turbulent, non-vaporizing region. The suggested differential pressures are

- a) just below the onset of cavitation (incipient cavitation) or the maximum available in the test facility, whichever is less (see IEC 60534-8-2);
- b) about 50% of the pressure differential of a);
- c) about 10% of the pressure differential of a).

The pressures shall be measured across the test section pressure taps with the valve at the selected travel.

For very small valve capacities, non-turbulent flow may occur at the recommended pressure differentials. In this case, larger pressure differentials shall be used to ensure turbulent flow. Flow tests should be conducted at conditions where the valve Reynolds Number, Re_v , (see equation (13)) is $100\,000$ or higher. If it is not possible to attain a minimum valve Reynolds Number of $100\,000$, then a compressible flow coefficient test should be considered (also see Annex D). Deviations and reason for the deviations from standard requirements shall be recorded.

For large valves where flow source limitations are reached, lower pressure differentials may be used optionally as long as turbulent flow is maintained. Deviations from standard requirements shall be recorded and the reasons for the deviations shall be indicated.

8.1.3 In order to keep the downstream portion of the test section filled with liquid and to prevent vaporization of the liquid, the absolute upstream pressure shall be maintained at a minimum of $2\Delta p/F_L^2$ or $p_{atm}+0,14$ bar, whichever is greater. If the liquid pressure recovery factor, F_L , of the test specimen is unknown, a conservative (i.e. low) estimate may be used. See Annex E of IEC 60534-2-1: 2011 for typical F_L values. Table 2 provides the minimum upstream pressures for selected values of Δp and F_L . The line velocity should not exceed 13,7 m/s to avoid vaporization in fresh water.

8.1.4 Flow tests shall be performed to determine:

- the rated flow coefficient C_R using 100 % of rated travel;
- inherent flow characteristics (optional), using 5 %, 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 % and 100 % of rated travel.

NOTE To determine the inherent flow characteristic more fully, flow tests may be performed at travel intervals less than 5 % of rated travel.

**Table 2 – Minimum inlet absolute test pressure
in kPa (bar) as related to F_L and Δp**

Δp kPa (bar) → F_L ↓	Minimum inlet absolute test pressure – kPa (bar)								
	35 (0,35)	40 (0,40)	45 (0,45)	50 (0,50)	55 (0,55)	60 (0,60)	65 (0,65)	70 (0,70)	75 (0,75)
0,5	280 (2,8)	320 (3,2)	360 (3,6)	400 (4,0)	440 (4,4)	480 (4,8)	520 (5,2)	560 (5,6)	600 (6,0)
0,6	190 (1,9)	220 (2,2)	250 (2,5)	270 (2,7)	300 (3,0)	330 (3,3)	360 (3,6)	380 (3,8)	410 (4,1)
0,7	150 (1,5)	160 (1,6)	180 (1,8)	200 (2,0)	220 (2,2)	240 (2,4)	260 (2,6)	280 (2,8)	300 (3,0)
0,8	150 (1,5)	160 (1,6)	160 (1,6)	170 (1,7)	170 (1,7)	190 (1,9)	200 (2,0)	220 (2,2)	230 (2,3)
0,9	150 (1,5)	160 (1,6)	160 (1,6)	170 (1,7)	170 (1,7)	180 (1,8)	180 (1,8)	190 (1,9)	190 (1,9)
NOTE 1 For large valves where flow source limitations are reached, lower pressure differentials may be used optionally as long as turbulent flow is maintained and differential pressure measurement accuracy is within specification.									
NOTE 2 For pressures not listed, use the following equation to calculate the upstream pressure: $p_{1,min} = 2\Delta p/F_L^2$.									

8.1.5 Record the following data:

- valve travel;
- inlet pressure p_1 ;
- pressure differential ($p_1 - p_2$) across the pressure taps;
- fluid inlet temperature T_1 ;
- volumetric flow rate Q ;
- barometric pressure;

- g) physical description of test specimen (i.e. type of valve, nominal size, pressure rating, flow direction);
- h) physical description of test system and test fluid;
- i) any deviations from the provisions of this standard.

Data shall be evaluated using the procedure in 9.3.

8.2 Test procedure for liquid pressure recovery factor F_L and combined liquid pressure recovery factor and piping geometry factor F_{LP}

8.2.1 The maximum flow rate $Q_{\max}$ (referred to as choked flow) is required in the calculation of the factors F_L (for a given test specimen without attached fittings) and F_{LP} (for a given test specimen which includes attached fittings). With fixed inlet conditions, choked flow is evidenced by the failure of increasing pressure differentials to produce further increases in the flow rate. The following test procedure shall be used to determine $Q_{\max}$. The data evaluation procedure is found in 9.4. The tests for F_L and corresponding C shall be conducted at identical valve travel. Hence, the tests for both of these factors at any valve travel shall be made while the valve is locked in a fixed position.

8.2.2 Install the test specimen without reducers or other attached devices in accordance with piping requirements in Figure 2 and Table B.3. A separate test shall be performed for each of the travels identified per 8.1.4. In each test the throttling element shall be positioned and secured at the desired value of travel.

8.2.3 The downstream throttling valve shall be in the wide-open position. With a preselected inlet pressure, the flow rate shall be measured and the inlet and outlet pressures recorded. This test establishes the maximum pressure differential ($p_1 - p_2$) for the test specimen in this test system. With the same inlet pressure, a second test shall be conducted with the pressure differential reduced to 90 % of the pressure differential determined in the first test. If the flow rate in the second test is within 2 % of the flow rate in the first test, the flow rate measured in the first test may be taken as $Q_{\max}$.

If not, repeat the test procedure at a higher inlet pressure. If $Q_{\max}$ cannot be achieved at the highest inlet pressure for the test system, use the following procedure. Calculate a value of F_L substituting the flow rate obtained at maximum obtainable values of inlet pressure and pressure differential. For the valve under test, report that F_L is greater than the value calculated as described in the previous sentence. See Annex E for a more detailed "long form" procedure.

8.2.4 Record the following data:

- a) valve travel;
- b) inlet pressure p_1 ;
- c) outlet pressure p_2 ;
- d) fluid inlet temperature T_1 ;
- e) volumetric flow rate Q ;
- f) barometric pressure;
- g) physical description of test specimen (i.e. type of valve, nominal size, pressure rating, flow direction);
- h) physical description of test system and test fluid;
- i) Any deviations from the provisions of this standard.

8.3 Test procedure for piping geometry factor F_p

The piping geometry factor modifies the valve flow coefficient C for fittings attached to the valve. The factor F_p is the ratio of C for a valve installed with attached fittings to the rated C of the valve installed without attached fittings and tested under identical service conditions. To obtain this factor, replace the valve with the desired combination of valve and attached fittings. Conduct flow tests according to 8.1 treating the combination as the test specimen for the purpose of determining test section pipe size. For example, a DN 100 valve between a reducer and an expander in a DN 150 line would use pressure tap locations based on a DN 150 line.

The data evaluation procedure is found in 9.5.

8.4 Test procedure for liquid critical pressure ratio factor F_F

The liquid critical pressure ratio factor F_F is almost exclusively a property of the fluid and its temperature. It is the ratio of the apparent *vena contracta* pressure at choked flow conditions to the vapour pressure of liquid at inlet temperature.

The quantity of F_F may be determined experimentally by using a test specimen for which F_L and C are known. The valve without attached fittings is installed in accordance with the piping requirements in Figure 2. The test procedure outlined in 8.2 for obtaining $Q_{\max}$ shall be used with the fluid of interest as the test fluid.

The data evaluation procedure is found in 9.6.

8.5 Test procedure for Reynolds number factor F_R for incompressible flow

To produce values of the Reynolds number factor F_R , non-turbulent flow conditions shall be established through the test valve. Such conditions will require low pressure differentials, high viscosity fluids, small values of C or F_d , or some combination of these. With the exception of valves with very small values of C , turbulent flow will always exist when flowing tests are performed in accordance with the procedure outlined in 8.1, and F_R under these conditions will have the value of 1,0.

Determine values of F_R by performing flowing tests with the valve installed in the standard test section without attached fittings. These tests should follow the procedure for C determination except that

- test pressure differentials may be any appropriate values provided that no vaporization of the test fluid occurs within the test valve;
- minimum upstream test pressure values shown in Table 2 may not apply if the test fluid is not fresh water at $20\text{ °C} \pm 14\text{ °C}$;
- the test fluid shall be a Newtonian fluid with a recommended viscosity considerably greater than that of water unless instrumentation is available for accurately measuring very low pressure differentials.

Perform a sufficient number of tests at each selected valve travel by varying the pressure differential across the valve so that the entire range of conditions, from turbulent to laminar flow, is spanned.

The data evaluation procedure is given in 9.7.

8.6 Test procedure for valve style modifier F_d

The valve style modifier takes into account the effect of trim geometry on the Reynolds number. It is defined as the ratio of the hydraulic diameter of a single flow passage to the diameter of a circular orifice, the area of which is equivalent to the sum of areas of all identical flow passages at a given travel.

The value of F_d should be measured at the desired travels. This value can only be measured when fully laminar flow is obtained using the test procedure outlined in 8.5.

Fully laminar flow is defined as a condition where $\sqrt{Re_v} / F_R$ is constant with a $\pm 5\%$ tolerance range (typically with Re_v values below 50).

The data evaluation procedure is given in 9.8.

9 Data evaluation procedure for incompressible fluids

9.1 Non-choked flow

The basic flow equation for non-choked, incompressible fluids is:

$$Q = N_1 F_R F_p C \sqrt{\frac{\Delta p}{\rho / \rho_0}} \quad (1)$$

For a valve installed without attached fittings, $F_p = 1$, and for turbulent flow conditions, $F_R = 1$.

9.2 Choked flow

9.2.1 For choked flow, two conditions shall be considered:

9.2.2 Without attached fittings

When the control valve is installed without attached fittings:

$$Q_{\max(L)} = N_1 F_L C \sqrt{\frac{p_1 - F_F p_v}{\rho / \rho_0}} \quad (2)$$

NOTE For a valve installed without attached fittings, the maximum pressure differential that is effective in producing flow under choked conditions is:

$$\Delta p_{\max(L)} = F_L^2 (p_1 - F_F p_v) \quad (3)$$

9.2.3 With attached fittings

When the control valve is installed with attached fittings:

$$Q_{\max(LP)} = N_1 F_p C \sqrt{\left(\frac{F_{LP}}{F_p}\right)^2 \left(\frac{p_1 - F_F p_v}{\rho / \rho_0}\right)} \quad (4)$$

The common form of equation (4) is:

$$Q_{\max(LP)} = N_1 F_{LP} C \sqrt{\left(\frac{p_1 - F_F p_v}{\rho / \rho_0}\right)} \quad (5)$$

NOTE For a valve installed with attached fittings, the maximum pressure differential that is effective in producing flow under choked conditions is:

$$\Delta p_{\max(\text{LP})} = \left(\frac{F_{\text{LP}}}{F_{\text{p}}} \right)^2 (p_1 - F_{\text{F}} p_{\text{v}}) \quad (6)$$

9.3 Calculation of flow coefficient C

The flow coefficient C may be calculated as K_{V} or C_{V} . See Table 3 for the appropriate value of N_1 , which will depend upon the coefficient selected and the pressure measurement unit.

Using the data obtained in 8.1, calculate C for each flow test using the equation:

$$C = \frac{Q}{N_1} \sqrt{\frac{\rho / \rho_0}{\Delta p}} \quad (7)$$

For water in the prescribed temperature range, $\rho / \rho_0 = 1$.

The flow coefficient at each travel shall be the arithmetic mean of the three test values rounded off to no more than three significant figures. The individual values used in computing the mean value should fall within $\pm 2,5$ % of the mean value.

9.4 Calculation of liquid pressure recovery factor F_{L} and the combined liquid pressure recovery factor and piping geometry factor F_{LP}

9.4.1 The factors F_{L} and F_{LP} shall be calculated using the data obtained in 8.2 and the following equations:

9.4.2 Without attached fittings

When the control valve is installed without attached fittings:

$$F_{\text{L}} = \frac{Q_{\max(\text{L})}}{N_1 C} \sqrt{\frac{\rho / \rho_0}{p_1 - F_{\text{F}} p_{\text{v}}}} \quad (8)$$

For fresh water in the prescribed temperature range, $\rho / \rho_0 = 1$ and $F_{\text{F}} = 0,96$. If fresh water is not used, ρ / ρ_0 and F_{F} for that fluid shall be used.¹

9.4.3 With attached fittings

When the control valve is installed with attached fittings:

$$F_{\text{LP}} = \frac{Q_{\max(\text{LP})}}{N_1 C} \sqrt{\frac{\rho / \rho_0}{p_1 - F_{\text{F}} p_{\text{v}}}} \quad (9)$$

For fresh water in the prescribed temperature range, $\rho / \rho_0 = 1$ and $F_{\text{F}} = 0,96$. If fresh water is not used, ρ / ρ_0 and F_{F} for that fluid shall be used.¹

¹ If the test fluid is a single component fluid it is permissible to use $F_{\text{F}} = 0,96 - 0,28 \sqrt{\frac{p_{\text{v}}}{p_{\text{c}}}}$.

9.5 Calculation of piping geometry factor F_p

Calculate F_p as follows using average values obtained in 8.3:

$$F_p = \frac{C_{\text{for valve installed with attached fittings}}}{C} = \frac{\frac{Q}{N_1} \sqrt{\frac{\rho/\rho_o}{\Delta p}}}{C} \quad (10)$$

For water in the prescribed temperature range, $\rho/\rho_o = 1$.

9.6 Calculation of liquid critical pressure ratio factor F_F

Calculate F_F as follows:

$$F_F = \frac{1}{p_v} \left[p_1 - (\rho/\rho_o) \left(\frac{Q_{\max}}{N_1 F_L C} \right)^2 \right] \quad (11)$$

where p_v is the fluid vapour pressure at the inlet temperature. $C F_L$ is determined for the test specimen by the standard method in 8.2.

9.7 Calculation of Reynolds number factor F_R

Use the test data, obtained as described under 8.5 and in equation (12) to obtain values of an apparent C . This apparent C is equivalent to $C F_R$. Therefore, F_R is obtained by dividing the apparent C by the experimental C determined for the test valve under conditions specified in 8.1 and at the same valve travel.

$$C F_R = \frac{Q}{N_1} \sqrt{\frac{\rho/\rho_o}{\Delta p}} \quad (12)$$

Although the data may be correlated in any manner suitable to the experimenter, a method that has proven to provide satisfactory correlations involves the use of the valve Reynolds number, which may be calculated from:

$$Re_v = \frac{N_4 F_d Q}{\nu \sqrt{C F_L}} \left(\frac{F_L^2 C^2}{N_2 d^4} + 1 \right)^{1/4} \quad (13)$$

where F_d is calculated as per 9.8.

9.8 Calculation of valve style modifier F_d

Using the data obtained in 8.5, calculate F_d using the following equation when $C/d^2 > 0,016 N_{18}$:

$$F_d = \frac{N_{26} \nu F_R^2 F_L^2 (C/d^2)^2 \sqrt{C F_L}}{Q \left(\frac{F_L^2 C^2}{N_2 D^2} + 1 \right)^{1/4}} \quad (14)$$

It is recommended that F_d be calculated at rated valve travel only. Significant errors may occur at reduced travel positions.

For reduced trim valves where $C/d^2 \leq 0,016 N_{18}$ at rated travel, F_d is calculated as follows:

$$F_d = \frac{N_{31} \nu F_R^2 F_L^2 \sqrt{CF_L}}{Q \left[1 + N_{32} \left(\frac{C}{d^2} \right)^{\frac{2}{3}} \right]} \quad (15)$$

The test shall be conducted at Re_v values of less than 100 or F_R values of less than 0,26. F_d values should be determined from a minimum of three tests and the values averaged.

10 Test procedure for compressible fluids

10.1 Test procedure for flow coefficient C

10.1.1 Determination of the flow coefficient C requires the following test procedure. Data shall be evaluated using the procedure in 11.1. An alternate procedure for calculating C is provided in 10.2.6.

10.1.2 Install the test specimen without attached fittings in accordance with the piping requirements in Figure 2.

10.1.3 Care should be exercised to ensure that the flow rate through the test specimen and the flow measurement device are in fact the same prior to recording data measurements. Compressible flow tests in blow down style of test facilities are potentially problematic, especially when testing valves with large capacities relative to the flow capability of the facility. In such instances the transient nature of the blow down may make it difficult to establish steady-state flow through the test manifold. Precautionary steps include:

- 1) allowing ample stabilization time after any system;
- 2) minimizing the distance between the test specimen and flow measurement device (within limits associated with installation practice of both devices);
- 3) imposing an upper limit on the maximum capacity valve that can be tested in the system.

Flow tests shall include flow measurements at three pressure differentials. In order to approach flowing conditions that can be assumed to be incompressible, the pressure differential ratio ($x = \Delta p/p_1$) shall be less than or equal to 0,02. It is also necessary to ensure that the flowing conditions are operating in the fully turbulent flow regime. A minimum valve Reynolds Number, Re_v , of 100 000 should be established for all test conditions (see equation (13)). Note that actual volumetric flow rate should be used in computing the Reynolds Number.

10.1.4 Flow tests shall be performed to determine:

- a) the rated flow coefficient C, using 100 % of rated travel;
- b) inherent flow characteristics (optional), using 5 %, 10 %, 20 %, 30 %, 40 %, 50 %, 60 %, 70 %, 80 %, 90 % and 100 % of rated travel.

NOTE To determine the inherent flow characteristics more fully, flow tests may be performed at travels less than 5 % of rated travel.

10.1.5 Record the following data:

- a) valve travel;
- b) inlet pressure p_1 ;
- c) pressure differential ($p_1 - p_2$) across pressure taps;

- d) fluid inlet temperature T_1 ;
- e) volumetric flow rate Q ;
- f) barometric pressure;
- g) physical description of test specimen (i.e. type of valve, nominal size, pressure rating, flow direction);
- h) physical description of test system and test fluid;
- i) any deviations from the provisions of this standard.

10.2 Test procedure for pressure differential ratio factors x_T and x_{TP}

10.2.1 The quantities x_T and x_{TP} are the terminal ratios of the differential pressure to absolute inlet pressure ($\Delta p/p_1$) for fluids with $F_\gamma = 1$ ($\gamma = 1,4$). However, these quantities can be obtained when using test gases for which F_γ does not equal 1 (provided γ falls within the range $1,2 \leq \gamma \leq 1,6$ per 7.2) as shown in equations (23) and (24). The maximum flow rate $Q_{\max}$ (referred to as choked flow) is required in the calculation of x_T (for a given test specimen without attached fittings) and x_{TP} (for a given test specimen with attached fittings). With fixed inlet conditions, choked flow is evidenced by the failure of increasing pressure differentials to produce further increases in the flow rate. Values of x_T and x_{TP} shall be calculated using the procedures in 11.2 and 11.3, respectively. An alternate procedure for determining x_T and x_{TP} is given in 10.2.6.

The following test procedure shall be used to determine $Q_{\max}$.

10.2.2 The test section of 5.2 shall be used, with the test specimen at 100 % of rated travel. Optional tests may be performed at other valve travels to more fully understand the possible variation of x_T and x_{TP} with valve travel.

10.2.3 Any upstream supply pressure sufficient to produce choked flow is acceptable, as is any resulting pressure differential across the test specimen provided the criteria of choked flow (specified in 10.2.4) are met.

10.2.4 The downstream throttling valve shall be in the wide-open position. With a preselected inlet pressure, the flow rate shall be measured and the inlet and outlet pressures recorded. This test establishes the maximum pressure differential ($p_1 - p_2$) for the test specimen in this test system. Using the same inlet pressure, a second test shall be conducted with the pressure differential reduced to 90 % of the pressure differential determined in the first test. If the flow rate of this second test is within 0,5 % of the flow rate for the first test, the flow rate measured in the first test may be taken as $Q_{\max}$. If not, repeat the test procedure at a higher inlet pressure.

In order to attain the prescribed accuracy, the flow rate instrument accuracy and repeatability requirements of 5.4 shall be followed. This series of tests shall be made consecutively, using the same instruments, and without alteration to the test set-up.

10.2.5 Record the following data:

- a) valve travel;
- b) inlet pressure p_1 ;
- c) outlet pressure p_2 ;
- d) fluid inlet temperature T_1 ;
- e) volumetric flow rate Q ;
- f) barometric pressure;
- g) physical description of test specimen (i.e. type of valve, nominal size, pressure rating, flow direction);

- h) physical description of test system and test fluid;
- i) any deviations from the provisions of this standard.

10.2.6 Alternative test procedure for pressure differential ratio factors x_T and x_{TP} and flow coefficient C

If a laboratory is unable to determine the x_T value for a valve using the procedure described above, this alternative procedure may be used.

The test section of 5.2 shall be used with the test specimen at 100 % of rated travel (or other travels of interest).

With a preselected inlet pressure, measurements shall be made of flow rate Q , fluid inlet temperature T_1 and downstream pressure for a minimum of five well-spaced values of x (the ratio of pressure differential to absolute inlet pressure).

From these data points, calculate values of the product $Y C$ using the equation:

$$YC = \frac{Q}{N_9 p_1} \sqrt{\frac{MT_1}{x}} \quad (16)$$

where Y is the expansion factor defined by:

$$Y = 1 - \frac{x}{3F_\gamma x_T} \quad (17)$$

in which $F_\gamma = \gamma/1,4$.

The test points shall be plotted on linear coordinates as $(Y C)$ versus x and a linear curve fitted to the data. If any point deviates by more than 5 % from the curve, additional test data shall be taken to ascertain that the specimen truly exhibits anomalous behaviour.

The value of C_o for the specimen shall be taken from the curve at $x = 0$, $Y = 1$.

At least one test point $(Y C)_1$ shall fulfil the requirement that $(Y C)_1 \geq 0,97 (Y C)_o$, where $(Y C)_o$ corresponds to $x \approx 0$.

At least one test point $(Y C)_n$ shall fulfil the requirement that $(Y C)_n \leq 0,83 (Y C)_o$.

The value of x_T for the specimen shall be taken from the curve at $(Y C) = 0,667 (Y C)_o$.

If this method is used, that fact shall be stated.

10.3 Test procedure for piping geometry factor F_p

The piping geometry factor modifies the valve flow coefficient C for fittings attached to the valve. The factor F_p is the ratio of C for a valve installed with attached fittings to the C of the valve installed without attached fittings and tested under identical service conditions.

To obtain this factor, replace the valve with the desired combination of valve and attached fittings. Then conduct the flow tests according to 10.1 treating the combination as the test specimen for the purpose of determining test section pipe size. For example, a DN 100 valve between a reducer and expander in a DN 150 line would use pressure tap locations based on a DN 150 line.

The data evaluation procedure is given in 11.5.

10.4 Test procedure for Reynolds number factor F_R

To establish values of the Reynolds number factor F_R , non-turbulent flow conditions shall be established through the test valve. Such conditions will typically only occur, using compressible fluid, if the C_R value is less than 0,5 for C_V or 0,43 for K_V .

Non-turbulent flow conditions are deemed to exist when, using the procedure outlined in 10.2, the amount of gas flow measured is still increasing even though $x \geq x_T$ for the specific valve, i.e., there is no choked flow.

In order to obtain such non-turbulent flow, the inlet pressure to the test specimen should be less than:

$$p_{1 \max} = \frac{0,035}{F_d \sqrt{C F_L}} \quad (18)$$

in bars, but no less than 2 bar absolute.

Determine values of F_R by carrying out flow tests with the valve installed in the standard test section without attached fittings. Carry out a sufficient number of tests at each selected valve travel by varying the inlet pressure so that the entire range from turbulent to laminar flow is spanned.

The data evaluation procedure is given in 11.6.

10.5 Test procedure for valve style modifier F_d

The valve style modifier accounts for the effect of trim geometry on the Reynolds number. It is defined as the ratio of the hydraulic diameter of a specific flow passage to the equivalent circular diameter of the total flow area.

The value of F_d should be measured at the desired travels. This value can only be measured when fully laminar flow is obtained using the test procedure given in 8.6.

Fully laminar flow is defined as a condition where $\sqrt{Re_V}/F_R$ is constant with a ± 5 % tolerance range (typically with Re_V values below 50).

The data evaluation procedure is given in 11.7.

10.6 Test procedure for small flow trim

Trim having a flow coefficient C less than 0,05 for C_V (0,043 for K_V) is defined as small flow trim. To ensure that the flow coefficient C for small flow trim is fully in the turbulent regime, the inlet pressure p_1 should be no less than the value given in the following equation:

$$p_1 = \frac{N_{21}}{F_d \sqrt{C F_L}} \quad (19)$$

where the outlet pressure is less than 0,3 p_1 . The test section of 5.2 shall be used with the test specimen at 100 % of rated travel. With constant inlet pressure, vary the outlet pressure to obtain three separate flow rates.

If the calculated inlet pressure per equation (19) is larger than the rated pressure of the test specimen, or beyond the capability of the test facility, the suitable alternative test method given in Annex D shall be used.

The data evaluation procedure is given in 11.8.

11 Data evaluation procedure for compressible fluids

11.1 Flow equation

The basic flow equation for compressible fluids is:

$$Q = N_9 F_p C p_1 Y \sqrt{\frac{x}{MT_1 Z}} \quad (20)$$

where

$$Y = 1 - \frac{x}{3F_\gamma x_T} \quad (21)$$

in which $F_\gamma = \gamma/1,4$.

For flow tests where no fittings are attached to the valve, $F_p = 1$.

For a control valve handling a gas different from air, the terminal value of x (i.e., $F_\gamma x_T$) shall be corrected in the term $F_\gamma x_T$. The value of x used in any of the sizing equations or the relationship for Y shall be held to this limit even though the actual pressure differential ratio is greater. In practice, the numerical value of Y will range from almost 1 for very low differential pressures to 0,667 for choked flow ($x = F_\gamma x_T$).

11.2 Calculation of flow coefficient C

The flow coefficient C may be calculated as K_v or C_v . See Table 3 for the appropriate value of N_9 which will depend upon the coefficient selected and the inlet pressure measurement unit.

Using the data obtained in 10.1 and assuming that $Y = 1$, calculate the flow coefficient C for each test point using:

$$C = \frac{Q}{N_9 p_1} \sqrt{\frac{MT_1}{x}} \quad (22)$$

For air, $M = 28,97$ kg/kmol.

The flow coefficient at each travel shall be the arithmetic mean of the three test values rounded off to no more than three significant figures. The individual values used in computing the mean value should fall within $\pm 2,5$ % of the mean value.

11.3 Calculation of pressure differential ratio factor x_T

Calculate x_T using the data obtained in 10.2:

When $x = F_\gamma x_T$, then $Q = Q_{\max(T)}$ and $Y = 0,667$.

$$x_T = \left[\frac{Q_{\max(T)}}{0,667 N_9 C p_1} \right]^2 \left[\frac{M T_1 Z}{F_\gamma} \right] \quad (23)$$

If air is used as the test fluid, $F_\gamma = 1$, $M = 28,97$ kg/kmol and $Z = 1$.

Best accuracy is achieved when the instantaneous values of p_1 and T_1 associated with the value of $Q_{\max}$ are used in equation (23).

11.4 Calculation of pressure differential ratio factor x_{TP}

Calculate x_{TP} using the data obtained in 10.2.

When $x = F_\gamma x_{TP}$, then $Q = Q_{\max(TP)}$ and $Y = 0,667$

$$x_{TP} = \left[\frac{Q_{\max(TP)}}{0,667 N_9 F_p C p_1} \right]^2 \left[\frac{M T_1 Z}{F_\gamma} \right] \quad (24)$$

If air is used as the test fluid, $F_\gamma = 1$, $M = 28,97$ kg/kmol and $Z = 1$.

11.5 Calculation of piping geometry factor F_p

Calculate F_p using average values obtained in 10.3.

$$F_p = \frac{C_{\text{for valve installed with attached fittings}}}{C} = \frac{\frac{Q}{N_9 p_1} \sqrt{\frac{M T_1}{x}}}{C} \quad (25)$$

If air is used as the test fluid, $M = 28,97$ kg/kmol.

11.6 Calculation of Reynolds number factor F_R for compressible fluids

Use test data, obtained as described under 10.4 and in equation (26) to obtain values of an apparent C . This apparent C is equivalent to $C F_R$. Therefore, F_R is obtained by dividing the apparent C by the experimental C determined for the test valve under standard conditions at the same valve travel.

$$C F_R = \frac{Q}{N_{22}} \sqrt{\frac{M T_1}{\Delta p (p_1 + p_2)}} \quad (26)$$

Although the data may be correlated in any manner suitable to the experimenter, a method that has proven to provide satisfactory correlations involves the use of the valve Reynolds number, which may be calculated from equation (13) where F_d is calculated as per 11.8.

11.7 Calculation of valve style modifier F_d

Using the data obtained in 10.5, calculate F_d using equation (14) or (15) as appropriate.

11.8 Calculation of flow coefficient C for small flow trim

Using the data obtained in 10.6, calculate C from the following equation and average the results:

$$C = \frac{Q}{N_{22}} \sqrt{\frac{MT_1}{0,75 p_1 \Delta p}} \quad (27)$$

Table 3 – Numerical constants N

Constant	Flow coefficient C		Formulae units					
	K_v	C_v	Q	p, Δp, p _v	ρ	T	d	v
N_1	$1,00 \times 10^{-1}$ 1,00	$8,65 \times 10^{-2}$ $8,65 \times 10^{-1}$	m ³ /h m ³ /h	kPa bar	kg/m ³ kg/m ³	–	–	–
N_4	$7,07 \times 10^{-2}$	$7,60 \times 10^{-2}$	m ³ /h	–	–	–	–	m ² /s
N_9 ($t_s = 0\text{ °C}$)	$2,46 \times 10^1$ $2,46 \times 10^3$	$2,12 \times 10^1$ $2,12 \times 10^3$	m ³ /h m ³ /h	kPa bar	–	K K	–	–
N_9 ($t_s = 15\text{ °C}$)	$2,60 \times 10^1$ $2,60 \times 10^3$	$2,25 \times 10^1$ $2,25 \times 10^3$	m ³ /h m ³ /h	kPa bar	–	K K	–	–
N_{18}	$8,65 \times 10^{-1}$	1,00	–	–	–	–	mm	–
N_{21}	$1,3 \times 10^{-3}$ $1,3 \times 10^{-1}$	$1,4 \times 10^{-3}$ $1,4 \times 10^{-1}$	–	kPa bar	–	–	–	–
N_{22} ($t_s = 0\text{ °C}$)	$1,73 \times 10^1$ $1,73 \times 10^3$	$1,50 \times 10^1$ $1,50 \times 10^3$	m ³ /h m ³ /h	kPa bar	–	K K	–	–
N_{22} ($t_s = 15\text{ °C}$)	$1,84 \times 10^1$ $1,84 \times 10^3$	$1,59 \times 10^1$ $1,59 \times 10^3$	m ³ /h m ³ /h	kPa bar	–	K K	–	–
N_{25}	$4,02 \times 10^{-2}$	$4,65 \times 10^{-2}$	–	–	–	–	mm	–
N_{26}	$1,28 \times 10^7$	$9,00 \times 10^6$	m ³ /h	–	–	–	–	m ² /s
N_{31}	$2,1 \times 10^4$	$1,9 \times 10^4$	m ³ /h	–	–	–	–	m ² /s
N_{32}	$1,40 \times 10^2$	$1,27 \times 10^2$	–	–	–	–	mm	–
NOTE Use of the numerical constants provided in this table together with the practical metric units specified in the table will yield flow coefficients in the units in which they are defined.								