IEC 60534-2-3

Edition 3.0 2015-12

INTERNATIONAL STANDARD

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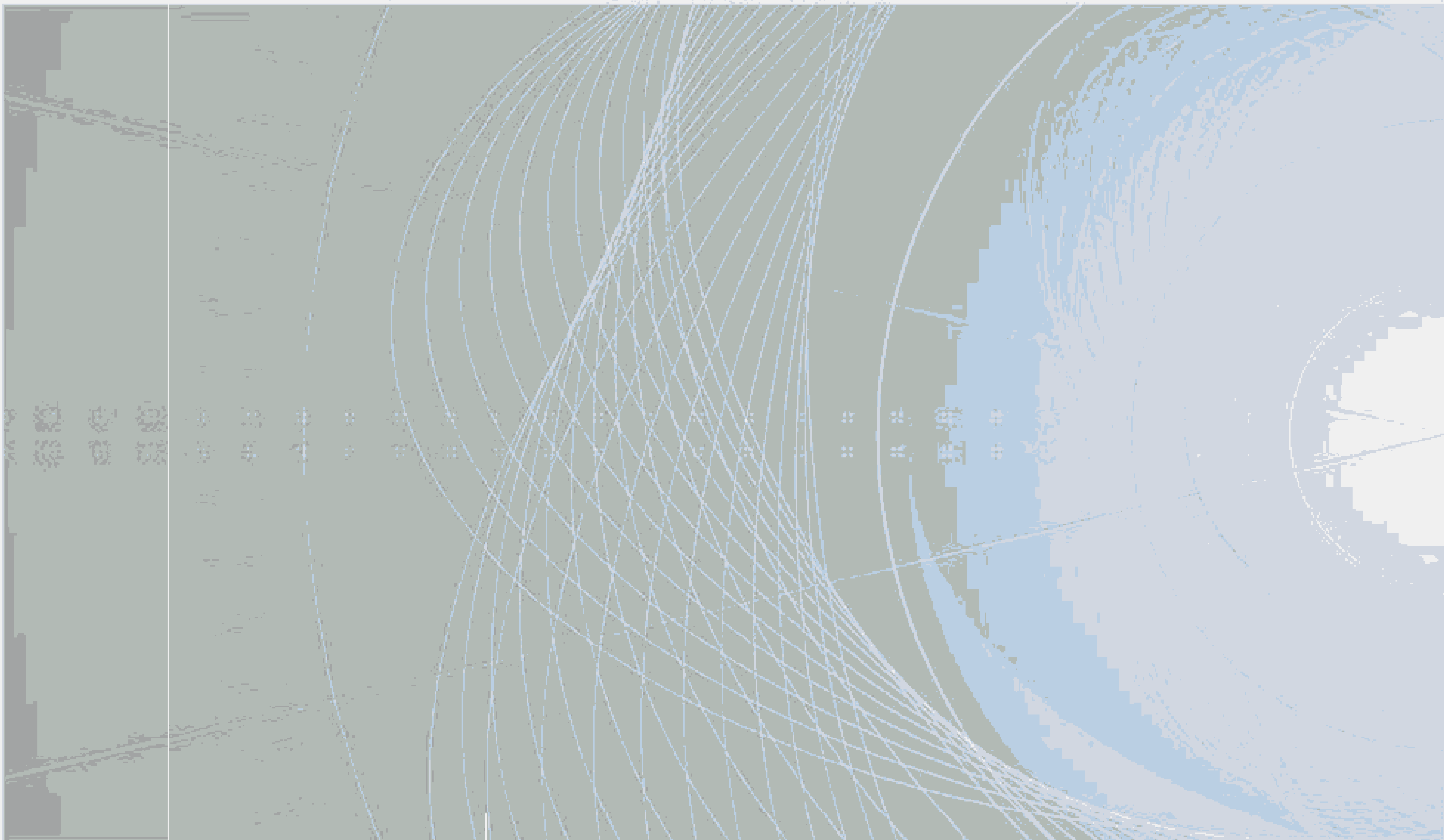
Industrial-process control valves –
Part 2-3: Flow capacity – Test procedures



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IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

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

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INDUSTRIAL-PROCESS CONTROL VALVES –

Part 2-3: Flow capacity – Test procedures

FOREWORD

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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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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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
Δp_{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 (ρ_1/ρ_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 bar = 10^2 kPa = 10^5 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} m^2/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 $C << N_{18}$) 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.

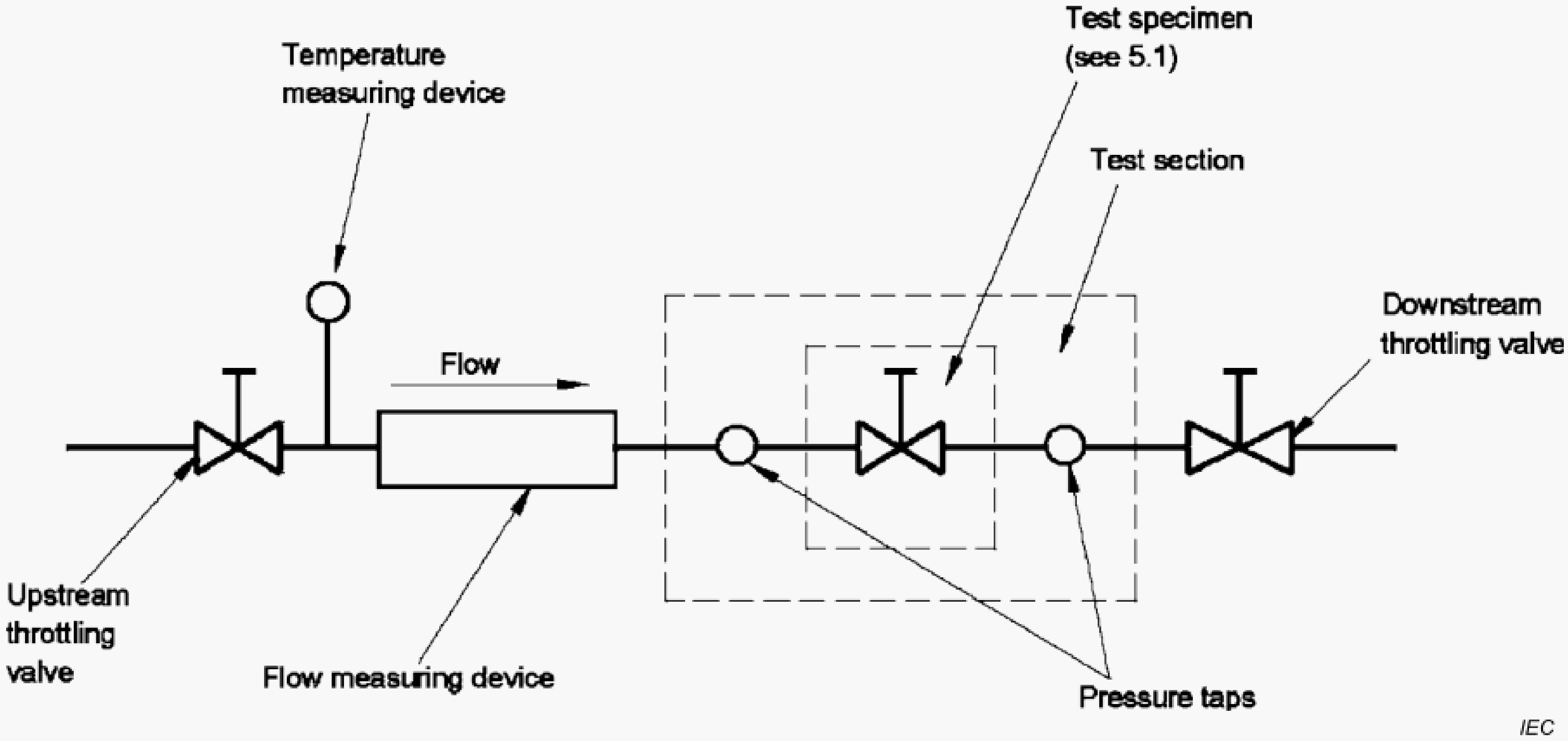


Figure 1 – Basic flow test system

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).

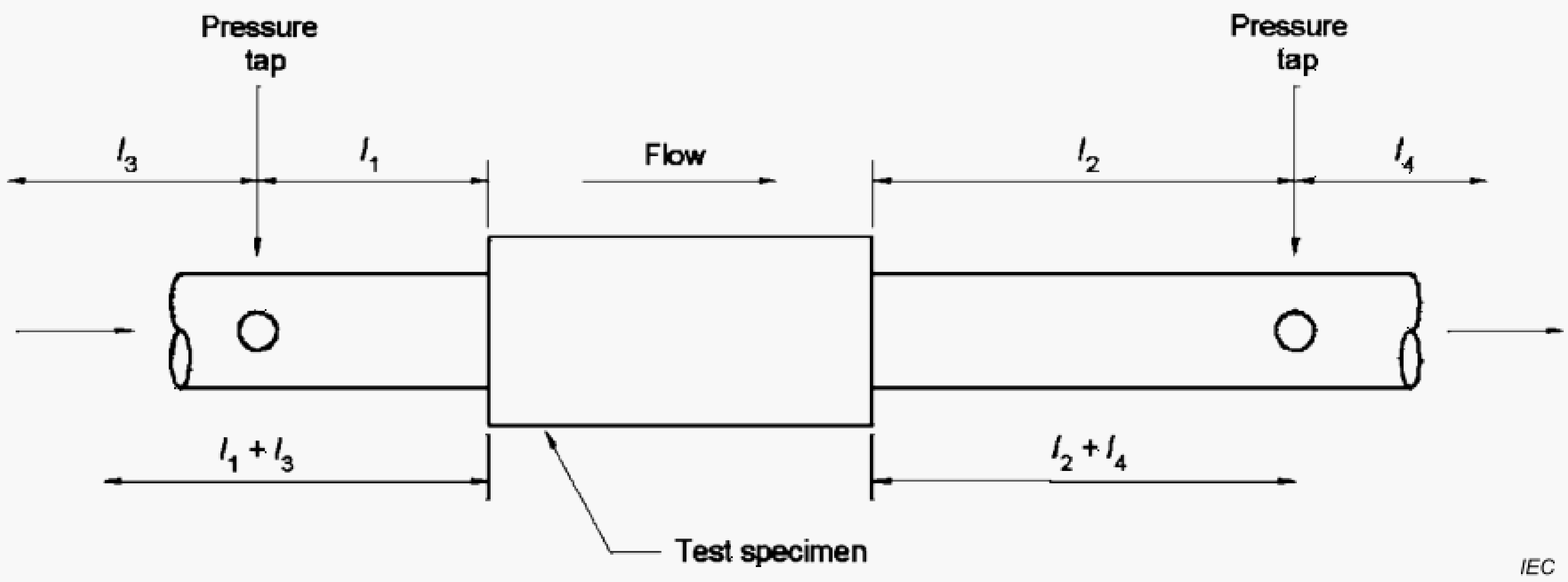
The inside diameter (ID) of the pipe normally should be within ± 2 % of the actual inside diameter of the inlet and outlet of the test specimen for all valve sizes. As the C/d^2 ratio (of the test valve) increases, the mismatch in diameters becomes more problematic. Potential pressure losses associated 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.

Standard test section configuration



Key

l_1 Two times nominal pipe diameter

l_2 Six times nominal pipe diameter

l_3 Eighteen times nominal pipe diameter minimum

l_4 One times nominal pipe diameter minimum

NOTE 1 Straightening vanes may be used where beneficial. If employed, the length l_3 may be reduced to not less than eight times the nominal pipe diameter. Information concerning flow conditioning can be found in ASME Performance Test Code PTC 19.5-2004, “Flow Measurement”.

NOTE 2 The location of the pressure taps are upstream and downstream of the test specimen as a whole. The test specimen may be simply the control valve or the control valve with any combination of attached fittings (see Annex A).

NOTE 3 If upstream flow disturbance consists of two elbows in series and they are in different planes, additional flow conditioning is required. See ASME Fluid meters for additional guidelines for line length.

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 ±2 % of actual output reading. The resolution and repeatability of the instrument shall be within ±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 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 ±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 ±1 °C (±2 °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 ±3 °C (±5 °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 ±0,5 % of the rated travel during any one specific flow test.

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

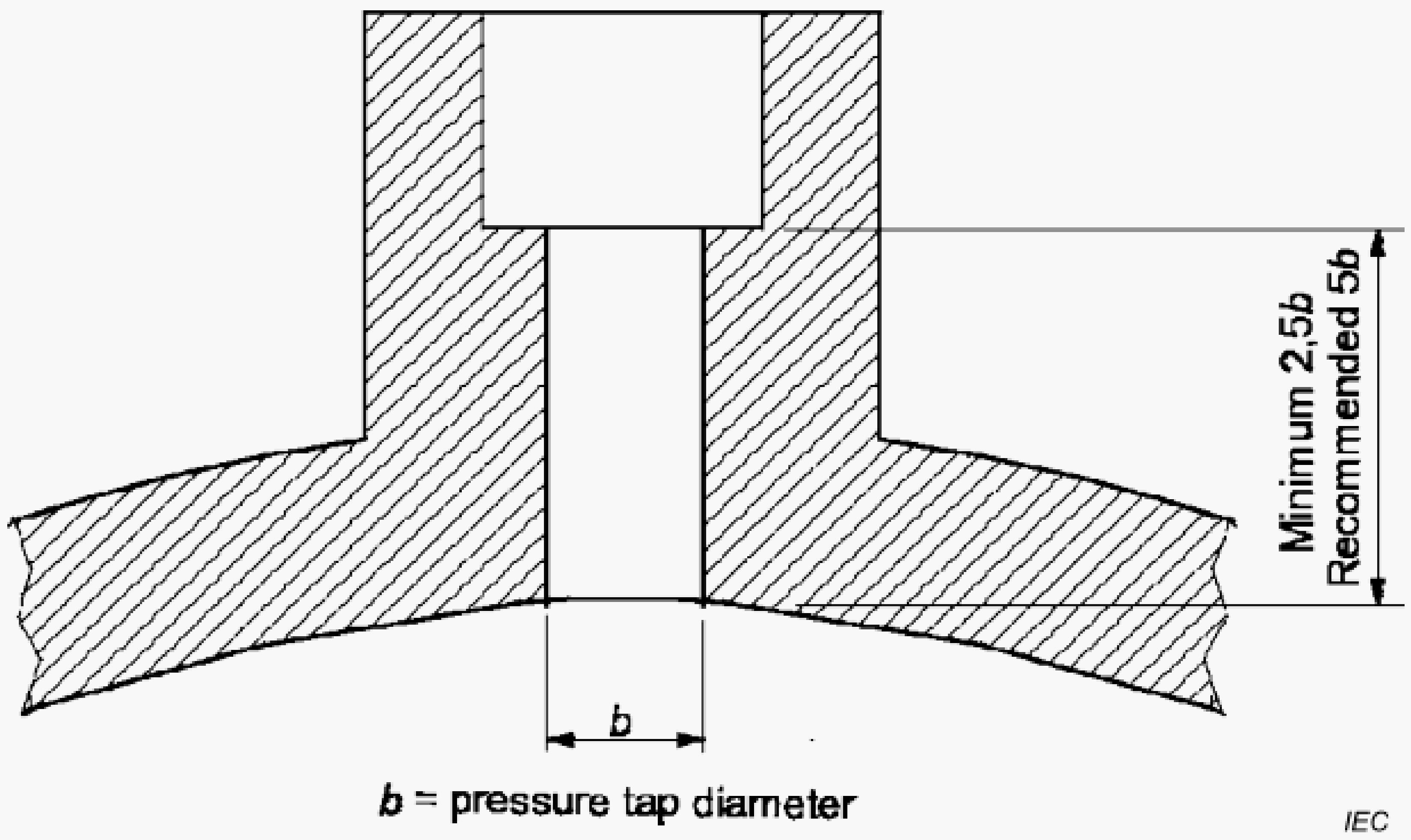
5.9 Installation of test specimen

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 ± 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 °C to 40 °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:

a) the rated flow coefficient C_R 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 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:

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

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

a) test pressure differentials may be any appropriate values provided that no vaporization of the test fluid occurs within the test valve;
b) minimum upstream test pressure values shown in Table 2 may not apply if the test fluid is not fresh water at 20 °C ± 14 °C;
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 ±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:

$$Q = N_1 F_R F_p C \sqrt{\frac{\Delta p}{\rho / \rho_o}} \tag{1}$$

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:

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

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

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

9.2.3 With attached fittings

When the control valve is installed with attached fittings:

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

The common form of equation (4) is:

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

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

$$\Delta p_{max(LP)} = \left(\frac{F_{LP}}{F_p}\right)^2 \left(p_1 - F_F p_v\right) \tag{6}$$

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:

$$C = \frac{Q}{N_1}\sqrt{\frac{\rho / \rho_o}{\Delta p}} \tag{7}$$

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

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 ±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:

$$F_L = \frac{Q_{max(L)}}{N_1 C}\sqrt{\frac{\rho / \rho_o}{p_1 - F_F p_v}} \tag{8}$$

For fresh water in the prescribed temperature range, $\rho/\rho_o = 1$ and $F_F = 0{,}96$. If fresh water is not used, ρ/ρ_o 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:

$$F_{LP} = \frac{Q_{max(LP)}}{N_1 C}\sqrt{\frac{\rho/\rho_o}{p_1 - F_F p_v}} \tag{9}$$

For fresh water in the prescribed temperature range, $\rho/\rho_o = 1$ and $F_F = 0{,}96$. If fresh water is not used, ρ/ρ_o and F_F for that fluid shall be used.[1]

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1 If the test fluid is a single component fluid it is permissible to use $F_F = 0{,}96 - 0{,}28\sqrt{p_v / p_c}$.

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.

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

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:

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

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 $C/d^2 > 0{,}016 N_{18}$:

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

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:

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

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 $1,2 \le \gamma \le 1,6$ 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:

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

where Y is the expansion factor defined by:

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

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:

$$p_{1\ max} = \frac{0{,}035}{F_d\sqrt{CF_L}} \qquad (18)$$

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:

$$p_1 = \frac{N_{21}}{F_d\sqrt{CF_L}} \qquad (19)$$

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:

$$Q = N_9 F_p C p_1 Y \sqrt{\frac{x}{M T_1 Z}} \tag{20}$$

where

$$Y = 1 - \frac{x}{3 F_\gamma x_T} \tag{21}$$

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:

$$C = \frac{Q}{N_9 p_1} \sqrt{\frac{M T_1}{x}} \tag{22}$$

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 ±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.

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

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 $Y = 0{,}667$

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

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.

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

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.

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

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:

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

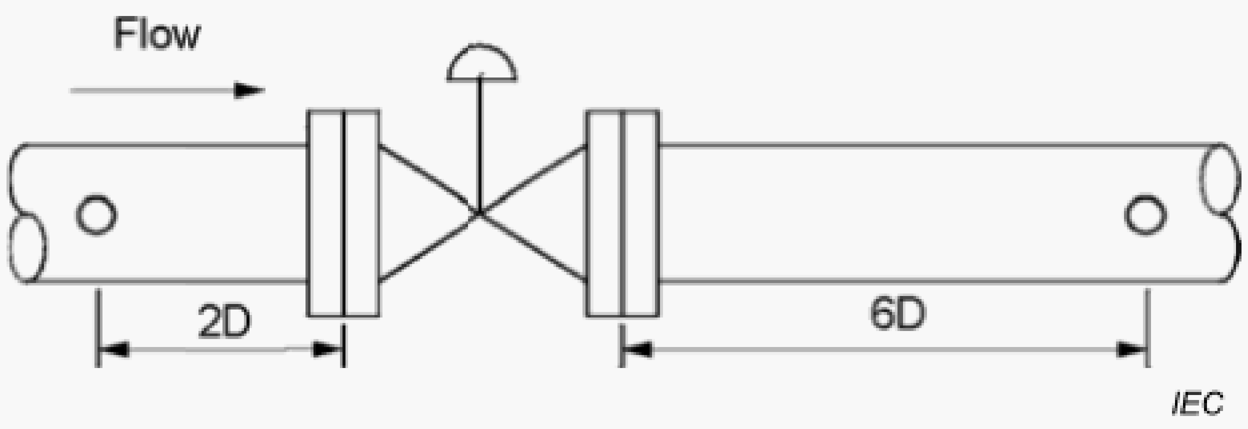
Table 3 – Numerical constants *N*

Constant	Flow coefficient *C*		Formulae units					
	K_v	C_v	Q	$p, \Delta p, p_v$	ρ	T	d	ν
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 °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 °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 °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 °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.								

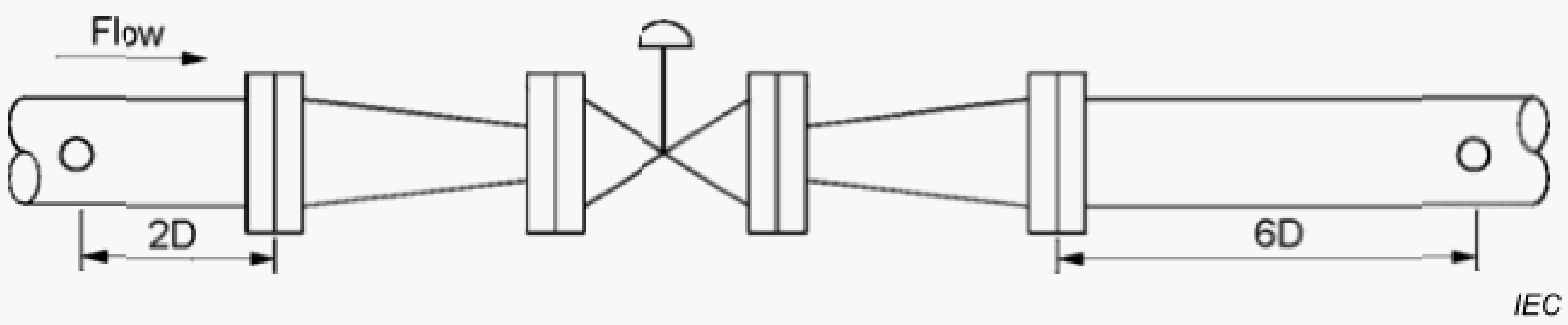
Annex A
(normative)

Typical examples of test specimens showing appropriate pressure tap locations

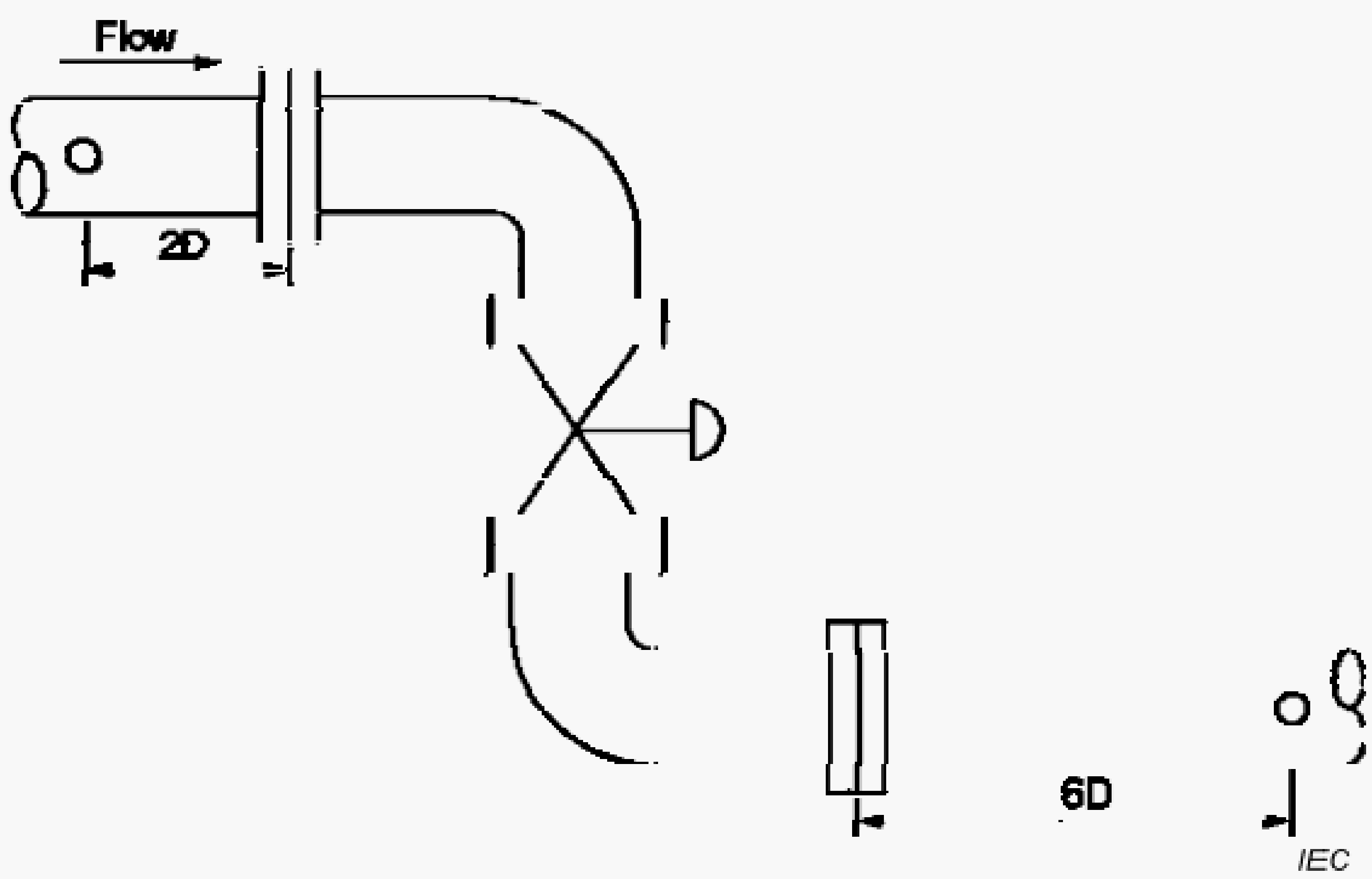
Contol valves are installed in a variety of configurations in service. Figure A.1 depicts several common configurations and the associated pressure tap locations.



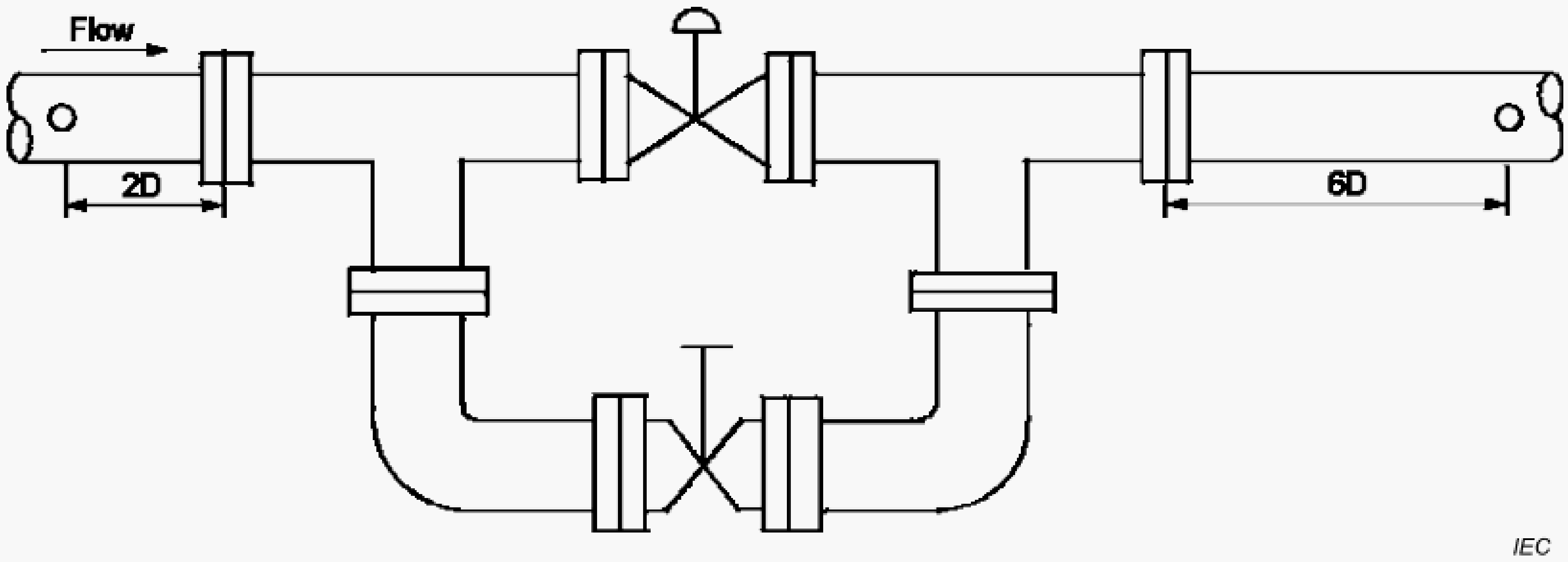
a) Control valve



b) Control valve with reducer and expander



c) Control valve with elbows



d) Control valve with by-pass

Figure A.1– Typical examples of test specimens showing appropriate pressure tap locations

It should be noted that all procedures and data reduction equations presented throughout this document assume that both the upstream pressure and downstream pressure tap locations fall in the same horizontal plane, i.e., elevation change between the tap locations is not included in the data reduction.

Annex B
(informative)

Engineering data

Engineering data for use in the calculations contained in this standard are given in the following tables. Fluid properties are presented in Table B.1 (fresh water) and Table B.2 (air). Pipe geometry data is presented in Table B.3.

Table B.1 – Properties for water

Temperature	Density	Dynamic viscosity	Kinematic viscosity	
°C	ρ/ρ_o	cP	cSt	m^2/s
5	1,000 865	1,518 1	1,518 2	1,5182E-06
10	1,000 600	1,305 9	1,306 3	1,3063E-06
15	1,000 000	1,137 5	1,138 6	1,1386E-06
20	0,999 104	1,001 6	1,003 4	1,0034E-06
25	0,997 943	0,890 1	0,892 7	8,9272E-07
30	0,996 544	0,797 3	0,800 8	8,0083E-07
35	0,994 926	0,719 3	0,723 6	7,2363E-07
40	0,993 108	0,653 0	0,658 1	6,5810E-07

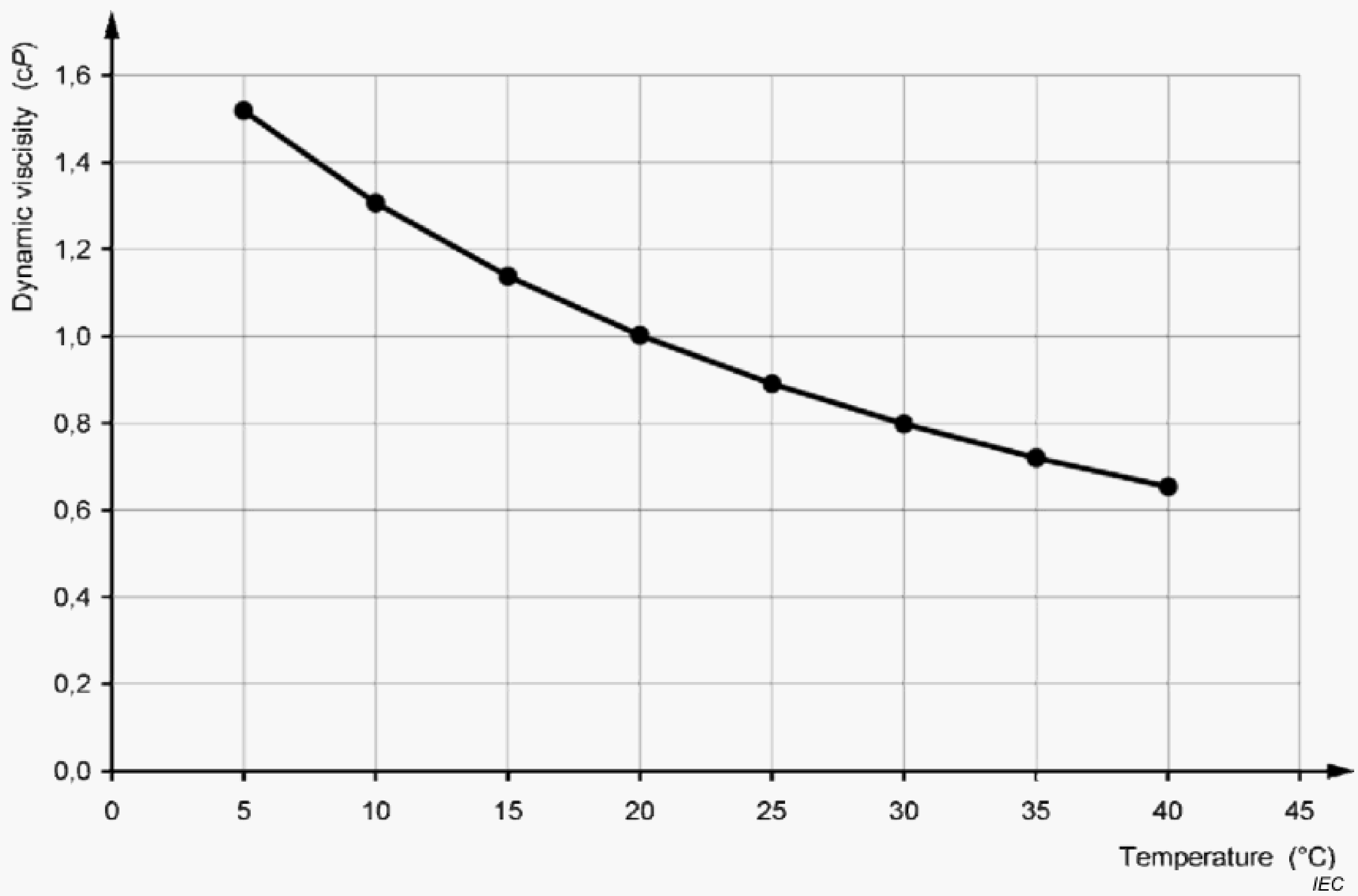


Figure B.1 – Dynamic viscosity of water

NOTE 1 To convert from dynamic to kinematic viscosity, divide by ρ. NOTE

2 To convert from centistokes to m^2/s, multiply by 1×10^{-6}.

Table B.2 – Properties of air

Temperature	Absolute viscosity	
°C	cP	Pa*s
5	0,017 26	1,723E-05
10	0,017 50	1,750E-05
15	0,017 74	1,774E-05
20	0,017 98	1,798E-05
25	0,018 22	1,822E-05
33	0,018 47	1,847E-05
35	0,018 71	1,871E-05
40	0,018 95	1,895E-05

NOTE 1 To convert from centistokes to m^2/s, multiply by 1×10^{-6}.

NOTE 2 To calculate the kinematic viscosity, use the equation below.

$$\nu = N\nu \mu \frac{T}{p}$$

where

ν is the the kinematic viscosity;

$N\nu$ is the a conversion constant depending on the unit used (see below);

μ is the the absolute (dynamic) viscosity;

T is the the absolute temperature of the air, and

p is the the absolute pressure of the air.

***N*ν**	***m***	***v***	***T***	***p***
2,871	cP	cS	K	bar
2,87E-03	Pa*sec	m^2/s	K	bar
2,87E-01	Pa*sec	m^2/s	K	kPa

Typical values of the valve coefficients different valve styles may be found in Annex D of IEC 60534-2-1:2011.

Table B.3 – Test section piping

Nominal pipe size (DN)	Pipe outside diameter mm	Nominal pipe wall thicknesses	
		PN 100 mm	Schedule 40 mm
Column 1	Column 2	Column 3	Column 4
10	17,2	2,3*	2,31
15	21,3	2,8*	2,77
20	26,9	2,9*	2,87
25	33,7	3,2	3,38
32	42,4	3,6	3,56
40	48,3	3,6	3,68
50	60,3	4,0	3,91
65	76,1	5,0	5,16
80	88,9	5,6	5,49
100	114,3	6,3	6,02
125	139,7	6,3	6,55
150	168,3	7,1	7,11
200	219,1	8,0	8,18
250	273,0	10,0	9,27
300	323,9	10,0	10,31

NOTE 1 Column 2 does not apply to tubes intended for threading according to ISO 7-1. Such tubes are set forth in ISO 65.

NOTE 2 All dimensions in columns 2 and 3 are taken from ISO 4200.

NOTE 3 Column 3 corresponds to Table 1, series F of ISO 4200:1991, except those marked with and asterisk where thicknesses are aligned to schedule 40 to the nearest 0,1 mm value. These thicknesses apply to rating up to and including PN 100.

NOTE 4 Column 4 thicknesses apply to rating up to and including Class 600 and correspond to schedule 40 converted into millimetres.

NOTE 5 The outside pipe diameter shown for DN65 is taken from ISO 4200 and corresponds to the 5,0 mm nominal pipe wall thickness shown in column 3. Other references show the outside pipe diameter value as 73,0 mm; this corresponds to the 5,16 mm nominal pipe wall thickness shown in column 4.

Annex C
(informative)

Derivation of the valve style modifier, F_d

All variables in Annex C have been defined in this part except for the following:

- A_o area of vena contracta of a single flow passage, in millimetres squared;
- d_H hydraulic diameter of a single flow passage, in millimetres;
- d_i inside diameter of annular flow passage (see Figure C.1), in millimetres;
- d_o equivalent circular diameter of the total flow area, in millimetres;
- D_o diameter of seat orifice (see Figure C.1 and Figure C.2), in millimetres;
- l_w wetted perimeter of a single flow passage, in millimetres;
- N_o number of independent and identical flow passages of a trim, dimensionless;
- α angular rotation of closure member (see Figure C.2), in degrees;
- β maximum angular rotation of closure member (see Figure C.2), in degrees;
- ζ_{B1} velocity of approach factor, dimensionless; and
- μ discharge coefficient, dimensionless.

The valve style modifier F_d, defined as the ratio d_H/d_o at rated travel and where $C_i/d^2 > 0{,}016\ N_{18}$ may be derived from flow tests using the following equation:

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

For valves having $C_i/d^2 \leq 0{,}016\ N_{18}$, F_d is calculated as follows:

$$F_d = \frac{N_{31}\,\nu\,F_L^2 F_R^2 \sqrt{C F_L}}{Q\left(N_{32}\left(\frac{C}{d^2}\right)^{2/3}+1\right)} \tag{C.2}$$

NOTE Values for N_{26} and N_{32} are listed in Table C.1.

Alternatively, F_d can be calculated by the following equation:

$$F_d = \frac{d_H}{d_o} \tag{C.3}$$

The hydraulic diameter, d_H, of a single flow passage is determined as follows:

$$d_H = \frac{4A_o}{l_w} \tag{C.4}$$

The equivalent circular diameter of the total flow area is given by the following equation:

$$d_o = \sqrt{\frac{4N_o A_o}{\pi}} \qquad \text{(C.5)}$$

F_d may be estimated with sufficient accuracy from dimensions given in manufacturers' drawings.

The valve style modifier for a single-seated, parabolic valve plug (flow tending to open) (see Figure C.1) may be calculated from equation (C.3).

From Darcy's equation, the area A_o is calculated from the following equation:

$$A_o = \frac{N_{23} C F_L}{N_o} \qquad \text{(C.6)}$$

NOTE Values for N_{23} are listed in Table C.1.

Therefore, since $N_o = 1$:

$$\begin{aligned} d_o &= \sqrt{\frac{4A_o}{\pi}} \\ &= \sqrt{\frac{4N_{23}CF_L}{\pi}} \end{aligned} \qquad \text{(C.7)}$$

$$\begin{aligned} d_o &= \frac{4A_o}{l_w} \\ &= \frac{4N_{23}CF_L}{\pi(D_o + d_i)} \end{aligned} \qquad \text{(C.8)}$$

$$\begin{aligned} F_d &= \frac{d_H}{d_o} \\ &= \frac{\dfrac{4N_{23}CF_L}{\pi(D_o + d_i)}}{\sqrt{\dfrac{4N_{23}CF_L}{\pi}}} \\ &= \frac{1{,}13\sqrt{N_{23}CF_L}}{D_o + d_i} \end{aligned} \qquad \text{(C.9)}$$

Where d_i varies with the flow coefficient. The diameter d_i is assumed to be equal to zero when $N_{23}CF_L = D_o^2$. At low C values, $d_i \approx D_o$; therefore,

$$d_i = D_o - \frac{N_{23}CF_L}{D_o} \qquad \text{(C.10)}$$

$$F_d = \frac{1{,}13\sqrt{N_{23}CF_L}}{2D_o - \dfrac{N_{23}CF_L}{D_o}} \tag{C.11}$$

The maximum F_d is 1,0.

For swing-through butterfly valves, see Figure C.2.

The effective orifice diameter is assumed to be the hydraulic diameter of one of the two jets emanating from the flow areas between the disk and valve body bore; hence $N_o = 2$.

The flow coefficient, C, at choked or sonic flow conditions is given as

$$N_{23}CF_L = \frac{0{,}125\pi D_o^2(\mu_1+\mu_2)\left(\dfrac{1-\sin\alpha}{\sin\beta}\right)}{\zeta_{B1}} \tag{C.12}$$

Assuming the velocity of approach facto $\zeta_{B1} = 1$, making $\mu_1 = 0{,}7$ and $\mu_2 = 0{,}7$, and substituting equation (C.6) into equation (C.12) yields the following:

$$A_o = \frac{0{,}55D_o^2\left(\dfrac{1-\sin\alpha}{\sin\beta}\right)}{N_o} \tag{C.13}$$

And since $\beta = 90°$ for swing-through butterfly valves,

$$A_o = \frac{0{,}55D_o^2(1-\sin\alpha)}{N_o} \tag{C.14}$$

However, since there are two equal flow areas in parallel,

$$A_o = 0{,}275D_o^2(1-\sin\alpha) \tag{C.15}$$

and,

$$d_o = \sqrt{\frac{4A_oN_o}{\pi}} = 0{,}837D_o\sqrt{1-\sin\alpha} \tag{C.16}$$

$$d_o = \frac{4A_o}{0{,}59\pi D_o} = 0{,}59D_o\sqrt{1-\sin\alpha} \tag{C.17}$$

NOTE $0{,}59\pi D_o$ is taken as the wetted perimeter, l_w, of each semi-circle allowing for jet contraction and hub.

$$F_d = \frac{d_H}{d_o} = 0{,}7\sqrt{1 - \sin\alpha} \quad (C.18)$$

Table C.1 – Numerical constant, *N*

Constant	Value	Formulae unit		
		Q	D	ν
N_{23}	$1{,}96 \times 10^1$	–	mm	–
N_{26}	$1{,}28 \times 10^7$	m^3/h	mm	m^2/s
N_{31}	$2{,}1 \times 10^4$	m^3/h	mm	m^2/s
NOTE Use of the numerical constant 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.				

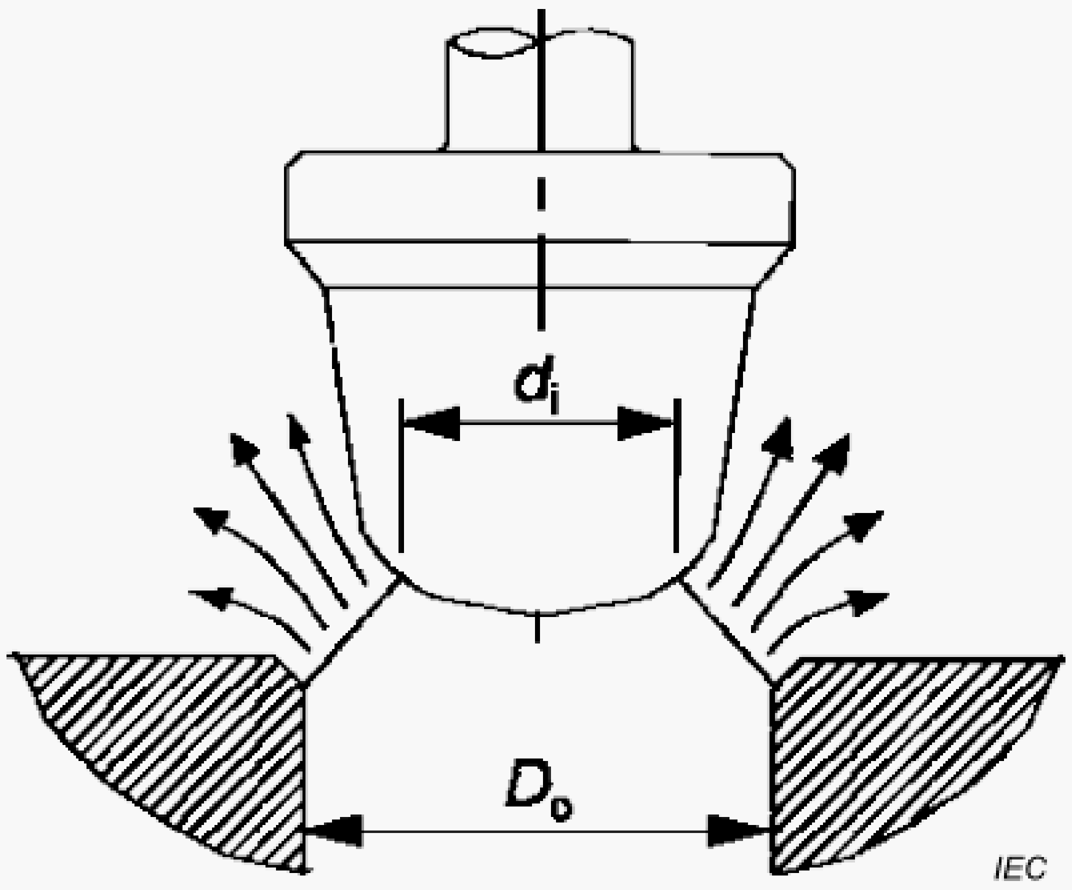


Figure C.1 – Single seated, parabolic plug (flow tending to open)

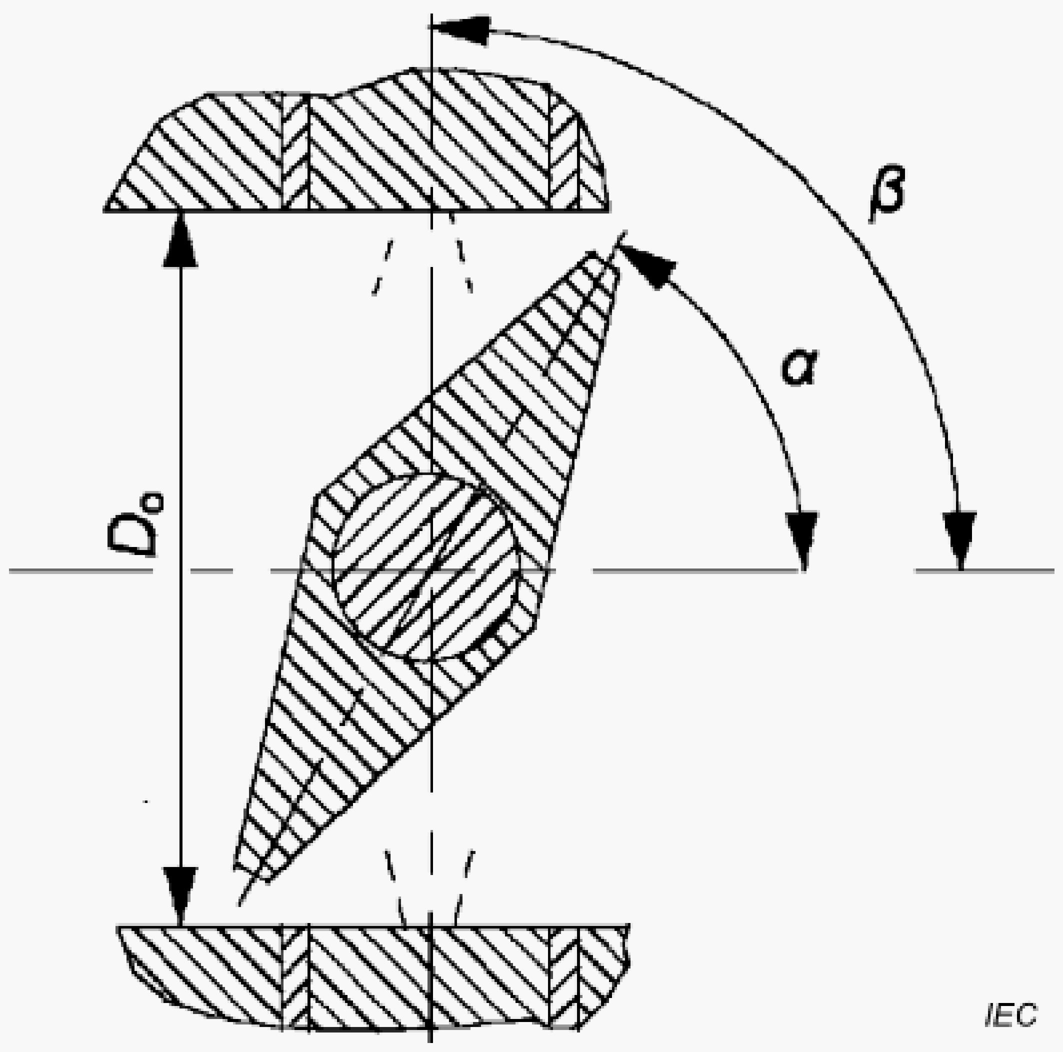


Figure C.2 – Swing-through butterfly valve

Annex D
(informative)

Laminar flow test discussion

The flow coefficient, *C* (C_v, K_v), is defined and normally measured under fully turbulent conditions. Establishing appropriate flow conditions for measuring the flow coefficient of very low flow valve trims can be difficult, however, especially when the coefficient on the order of 0,01 or less. While there is agreement that nonturbulent flow for such valves can be adequately predicted, a universally accepted approach within the industry is currently lacking. It follows that there is diversity in the approach to measuring the coefficients defined in this standard.

The flow test regimes and fluids in order of preference are:

1) turbulent flow with water;
2) turbulent flow with compressible media;
3) turbulent choked flow with compressible media;
4) laminar flow with compressible media.

In addition to ANSI/ISA-75.01.01-2012, several references for the interested reader are listed in the Bibliography at the end of the document.

Annex E
(informative)

Long form F_L test procedure

E.1 General

The following is a description of an alternate method of evaluating the liquid pressure recovery factor, F_L. Referred to herein as the "long form" method, it expands the data set upon which the F_L value is determined. The advantage of this method is that it renders a more comprehensive characterization of flow over the full domain of pressure drop ratio. These results can reveal important information regarding the behaviour of the valve that may not be apparent in the abbreviated "standard" version.

E.2 Test procedure

E.2.1 The test specimen shall be installed in a test system as prescribed by Clause 5 of this standard. The test shall be conducted utilizing an incompressible test fluid as specified in 7.1. All data shall be collected and recorded per 8.1.5.

E.2.2 The valve travel shall be set to the desired value and the maximum flow rate and pressure difference established in accord with the procedure described in 8.2.3 of this standard.

E.2.3 Additional test pressure differentials shall be established such that 10 to 15 data points exist uniformly over the full test pressure differential range (zero to the maximum differential established in E.2.2). Beginning at the choked flow condition, steady state flow shall be established at each pressure differential in decreasing order and data recorded.

E.2.4 If the test procedure is disrupted for any reason, the initial test pressure differential on resuming testing shall be established by exceeding the target value by a minimum of 10 % and decreasing the pressure drop to the desired value.

E.2.5 The preliminary data shall be reduced per Clause E.3 below and additional test runs conducted as needed to fully define the flow profile of the test specimen. In particular, additional data points should be collect at inflection points on the resulting curve, or near regions of high curvature.

E.3 Graphical data reduction

E.3.1 The value of F_L is established by determining the common pressure differential solution to the incompressible volumetric flow equation,

$$Q = N_1 C \sqrt{\frac{\Delta p}{\rho / \rho_o}} \tag{E.1}$$

and the incompressible choked flow equation,

$$Q = Q_c \tag{E.2}$$

This value is substituted into the defining F_L expression:

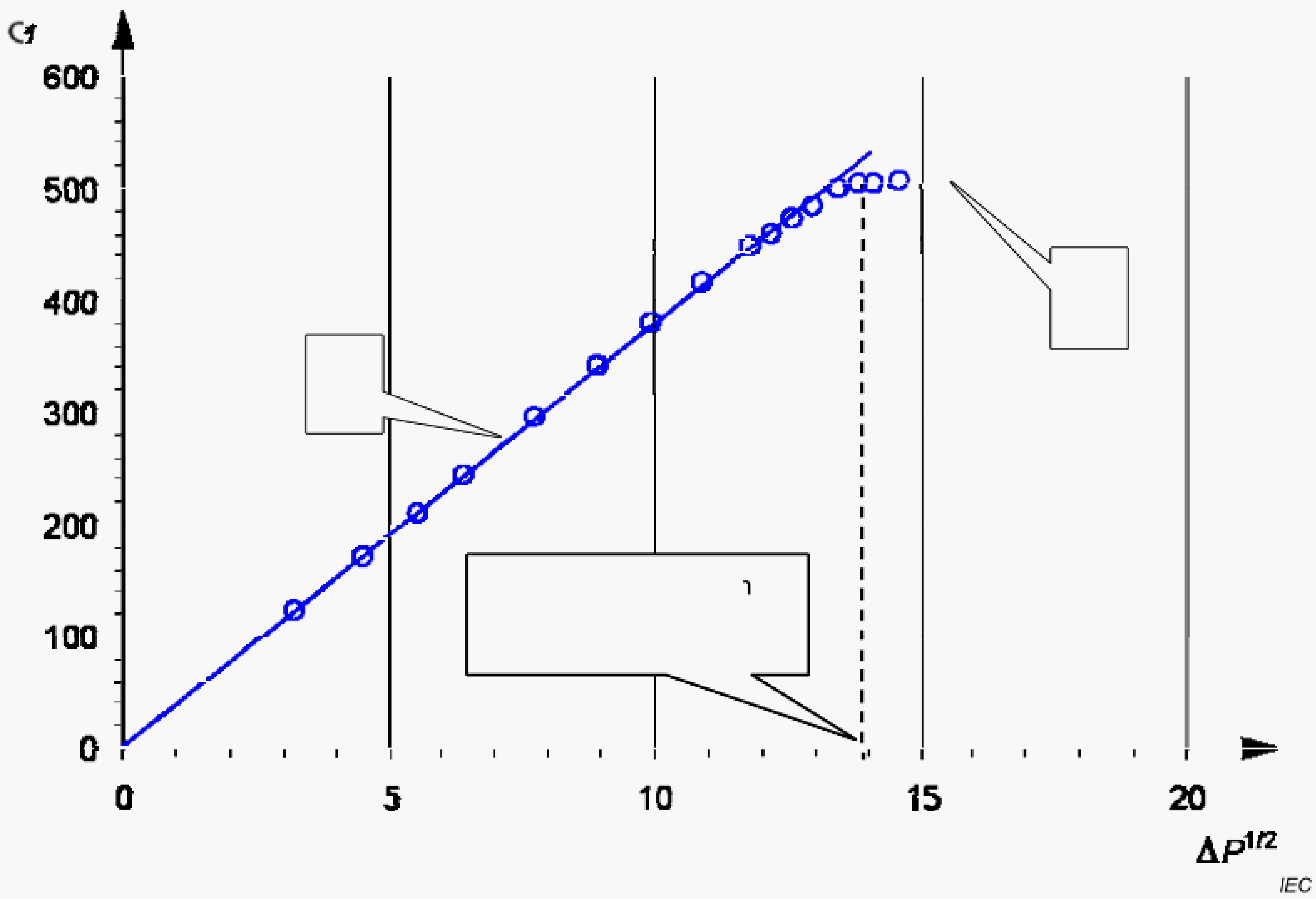
$$F_L = \sqrt{\frac{\Delta p}{p_1 - F_F\, p_v}} \tag{E.3}$$

to yield

$$F_L = \left(\frac{Q_c}{N\, C}\right)\sqrt{\frac{\rho/\rho_o}{p_1 - F_F p_v}} \tag{E.4}$$

The mechanics of analyzing the flow data is centred on establishing representative values for the choked flow rate, Q_c, and incompressible flow coefficient, C, values in equation (E.4). The procedure presented herein is graphically based to illustrate the principals underlying data reduction. It is recognized that a variety of regression schemas can be employed to automate the procedure.

E.3.2 The results of the testing should be imaged by plotting flow rate, Q, vs. the square root of the applied pressure differential as shown Figure E.1.



Key

A choked flow region

B linear, incompressible region

Figure E.1 – Typical flow results

E.3.3 A straight line representative of the choked flow rate should be established on the basis of the data and the value of Q_C noted (line A, Figure E.1).

E.3.4 A second straight line representative of the incompressible portion of the flow curve should be established (line B, Figure E.1). The line should pass through the origin of the graph and represent the data throughout the incompressible region. The slope of this line corresponds to the incompressible flow coefficient, C. The value of C as determined in 8.1 may alternatively be used to establish the slope of the curve.

E.3.5 The value of Q_c and C resulting from the graphical analysis is used in conjunction with equation (E.4) to compute the value of F_L.

NOTE The value of F_L and the value of C_v used to evaluate F_L constitute a matched pair of values. Published data values of F_L should be consistent with published values of C.

Annex F
(informative)

Calculation of F_P to help determine if pipe/valve port diameters are adequately matched

NOTE The term “port” in the context of the following discussion refers to “the opening of a valve’s inlet or outlet passageways” per ANSI/ISA-75.05.01-2000 (R2005), 3.120 (2).

As mentioned in 5.2, the valve and pipe port diameters shall be matched closely enough to not introduce significant errors in the calculations. This, of course, assumes that the intent is the most common one where the upstream and downstream piping is the same size as the valve. If the characteristics of a particular valve/pipe configuration where some or all of the piping is not the same size as the valve are desired, one of the goals would be the calculation of a pipe geometry factor, F_P, as described in 8.3; otherwise the upstream and downstream piping should match. Matching pipe and valve port inside diameters is often not difficult with ordinary pipe sizes and schedules but in some cases, such as the testing of a very high pressure valve with small port inside diameters, special piping may be required. This standard specifies a method for determining the suitability of pipe inside diameters. Subclause 5.2 specifies that the estimated piping geometry factor, calculated using formulas given in IEC 60534-2-1: 2011 and repeated below for convenience, shall be within the range 0,99 to 1,02, i.e. $0,99 \leq F_P \leq 1,01$. F_P is calculated from

$$F_P = \frac{1}{\sqrt{1+\frac{\sum\zeta}{N_2}\left(\frac{C}{d^2}\right)^2}} \qquad \text{(F.1)}$$

where $\sum\zeta$ is the sum of upstream and downstream Bernoulli coefficients and loss coefficients. They are calculated using equations (F.2) through (F.6) below and are adaptations of equations (16) through (20) of IEC 60534-2-1: 2011.

$$\sum\zeta = \zeta_1 + \zeta_2 + \zeta_{B1} - \zeta_{B2} \qquad \text{(F.2)}$$

$$\zeta_{B1} = 1 - \left(\frac{d}{D_1}\right)^4 \qquad \text{(F.3)}$$

$$\zeta_{B2} = 1 - \left(\frac{d}{D_2}\right)^4 \qquad \text{(F.4)}$$

$$\zeta_1 = 0,5\left[1 - \left(\frac{d}{D_1}\right)^2\right]^2 \qquad \text{(F.5)}$$

$$\zeta_1 = \left[1 - \left(\frac{d}{D_2}\right)^2\right]^2 \qquad \text{(F.6)}$$

The subscripts 1 or 2 indicate upstream or downstream factors respectively. Note that for the purpose of determining F_P here, the valve diameter, d, shall be the actual inside diameter of the associated valve port and not the valve nominal diameter. The pipe diameters D_1 and D_2 are pipe inside diameters.

Two cases are probably most common in testing according to this standard – (1) the upstream and downstream pipe inside diameters are the same size and larger that the valve port inside diameters and (2) the upstream pipe inside diameter is the same size as the valve inside diameter but the downstream pipe inside diameter is larger. Tables F.1 and F.2 below, tabulate F_P factors for those two cases as a function of the ratios d/D and $\frac{C}{d^2\sqrt{N_2}}$. Note that the large number of digits displayed were included to help verify hand or computer calculations and not imply high accuracy.

Table F.1 – Tabulated values of F_P if upstream and downstream pipe the same size

$\frac{C}{d^2\sqrt{N_2}}$	d/D_1 or d/D_2				
	1	**0,95**	**0,9**	**0,85**	**0,8**
0,05	1	0,999 982	0,999 932	0,999 856	0,999 757
0,1	1	0,999 929	0,999 729	0,999 423	0,999 029
0,2	1	0,999 715	0,998 919	0,997 698	0,996 135
0,3	1	0,999 359	0,997 572	0,994 842	0,991 365
0,4	1	0,998 861	0,995 696	0,990 885	0,984 802
0,5	1	0,998 222	0,993 299	0,985 867	0,976 551
0,6	1	0,997 443	0,990 393	0,979 835	0,966 744
0,7	1	0,996 525	0,986 992	0,972 848	0,955 525
0,8	1	0,995 468	0,983 11	0,964 968	0,943 054
0,9	1	0,994 275	0,978 765	0,956 265	0,929 493
1	1	0,992 946	0,973 977	0,946 811	0,915 008

Table F.2 – Tabulated values of F_P if downstream pipe larger than valve

$\frac{C}{d^2\sqrt{N_2}}$	d/D_2				
	1	**0,95**	**0,9**	**0,85**	**0,8**
0,05	1	1,000 22	1,000 385	1,000 502	1,000 576
0,1	1	1,000 881	1,001 543	1,002 011	1,002 312
0,2	1	1,003 538	1,006 213	1,008 118	1,009 345
0,3	1	1,008 015	1,014 146	1,018 548	1,021 404
0,4	1	1,014 383	1,025 573	1,033 71	1,039 036
0,5	1	1,022 752	1,040 848	1,054 237	1,063 108
0,6	1	1,033 267	1,060 479	1,081 069	1,094 934
0,7	1	1,046 122	1,085 177	1,115 585	1,136 505
0,8	1	1,061 569	1,115 938	1,159 84	1,190 908
0,9	1	1,079 93	1,154 176	1,216 981	1,263 142
1	1	1,101 623	1,201 944	1,292 058	1,361 837

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Available from: **IEC**

3, rue de Varembé
P.O. Box 131
1211 Geneva 20
Switzerland
Tel: + 41 22 919 02 11

ISO

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Available from: **ISO**

International Organization for Standardization
ISO Central Secretariat
Chemin de Blandonnet 8
CP 401
1214 Vernier, Geneva
Switzerland
Tel: + +41 22 749 01 11

ISA

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Available from: **ISA**

67 Alexander Drive
PO Box 12277
Research Triangle Park, NC 27709
Tel: (919) 990-9200

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Three Park Avenue
New York, NY 10016-5990
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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch