Valve sizing sample problems

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General information

These application notes provide a simplified procedure for sizing control valves at standard service conditions.

The data required to size a valve, such as the nominal size, nominal pressures and K_{VS}, is contained in the SAMSON data sheets for self-operated regulators and control valves.

Self-operated regulators and control valves can be sized accurately using the DIN IEC 534 procedure. For most applications, however, the following sizing equations formulated in the VDI/VDE Guideline 2173 provide a sufficient degree of accuracy.

In order to calculate the valve flow coefficient $\mathbf{K_V}$, the operating data specified in the figure to the right is required.

Typical sizing coefficients

Explanatory notes

Control valves and self-operated regulators

Rated travel · The rated travel H_{100} is the amount of movement of the valve closure member from the closed position to the designated full open position published by the manufacturer for each control valve series.

$\mathbf{K_V}$ · The valve flow coefficient K_V is defined as the number of cubic meters per hour (volume flow rate $\dot{V}$) of 5 to 30 °C water that will flow through a control valve at a specified travel H with a differential pressure ($\Delta p = p_1 - p_2$) of 10^5 Pa (1 bar) across it.

$\mathbf{K_{VS}}$ · The K_{VS} value is the expected flow coefficient K_V of the valve at rated travel H_{100} indicated and published by the manufacturer for each valve type (series).

$\mathbf{K_{V100}}$ · The K_{V100} value is the effective (actual) flow coefficient K_V of the valve at rated travel H_{100}. It must not deviate by more than ±10 % from the indicated K_{VS} value.

Self-operated regulators

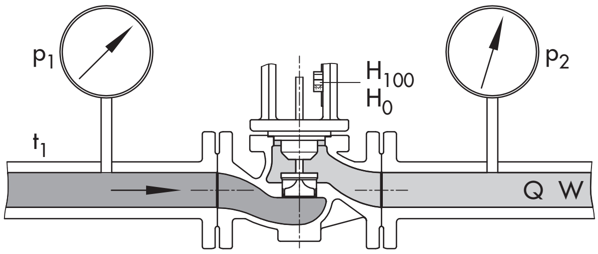
Self-operated flow regulators can only be sized if the upstream pressure p_1 is constant.

Safety factor $S = \frac{K_{VS}}{K_V}$

K_{VS}: Indicated K_{VS}
K_V: Calculated K_V

For self-operated regulators: $S \approx 1.3$ to 5

To ensure the proper operation of a self-operated regulator, the **kinematic viscosity** ν if the medium to be controlled must not exceed $1 \cdot 10^{-4}$ m²/s = 100 cSt.



p_1	Upstream pressure in bar
p_2	Downstream pressure in bar
Δp	Differential pressure ($p_1 - p_2$) across the valve in bar
H	Travel in mm
$\dot{V}$	Volume flow rate in m³/h
W	Mass flow rate in kg/h
ρ	Density (general) in kg/m³
ρ_1	Upstream density (for gases and steam) in kg/m³
t_1	Upstream temperature in °C

Fig. 1 · Operating data for determining the K_V value

Conversion of the maximum volume flow rate for liquids with different densities

$$\dot{V}_B = \dot{V}_A \cdot \left(\sqrt{\frac{\rho_A}{\rho_B}}\right)$$

ρ Density in kg/m³
$\dot{V}$ Volume flow rate in m³/h

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Liquid service

Equation (1) generally applies to liquids:

$$\dot{V} = K_V \cdot \sqrt{\frac{1000 \cdot \Delta p}{\rho}} \quad (1)$$

This equation contains the dimensional factor 1.

Diagram 1 shows the relationship between $\dot{V}$, K_V and Δp for liquids that have a density of ρ = 1000 kg/m³ at a temperature of t = 20 °C.

Flow regulators · Differential pressure across the valve

Calculate the minimum required differential pressure across the valve using Equation (2):

$$\Delta p_{min} = \Delta p_{restriction} + \left(\frac{\dot{V}}{K_{VS}}\right)^2 \quad (2)$$

Symbols and units

p_1, p_2	Absolute pressure in bar
Δp	In bar
ρ	Density in kg/m³
$\dot{V}$	Volume flow rate in m³/h
K_V	K_V in m³/h
Δp_{min}	Minimum differential pressure across the valve in bar
$\Delta p_{restriction}$	Differential pressure in bar created deliberately across the restriction in the flow path for flow measurement purposes
K_{VS}	Indicated valve sizing coefficient in m³/h

Sizing sample problem 1

Determine: Min. differential pressure Δp across fully open valve

Given: Type 42-36 Self-operated Flow Regulator, diff. pressure across restriction 0.2 bar, DN 40, K_{VS} 20, volume flow rate

Solution: Calculate Δp_{min} using Equation (2):

$$\Delta_{min} = \Delta p_{restriction} + \left(\frac{\dot{V}}{K_{VS}}\right)^2 \quad (2)$$

$\Delta p_{restriction}$ = 0.2 to 0.5 bar depending on regulator version

K_{VS} = 20 m³/h

$\Delta_{restriction}$ = 0.2 bar

$\dot{V}$ = 10 m³/h

$$\Delta p_{min} = 0.2 + \left(\frac{10}{20}\right)^2 = \mathbf{0.45\ bar}$$

Sizing sample problem 2

Determine: Volume flow rate of acetone (m³/h) with valve fully open

Given: Type 3241-1 Pneumatic Control Valve, DN 40, differential pressure $\Delta p = p_1 - p_2$ · Density of acetone in kg/m³

Solution:

Calculate $\dot{V}$ using Equation (1):

$$\dot{V} = K_{VS} \cdot \sqrt{\frac{1000 \cdot \Delta p}{\rho}} \quad (1)$$

K_{VS} = 25 m³/h 1)

Δp = $p_1 - p_2$ = 0.5 bar

ρ = 800 kg/m³

$$\dot{V} = 25 \cdot \sqrt{\frac{1000 \cdot 0.5}{800}} = \mathbf{19.76\ m^3/h}$$

1) K_{VS} and hence also $\dot{V}$, the calculated volume flow rate, have a permissible tolerance of ±10 %.

Sizing sample problem 3

Determine: Type … Pressure Reducing Valve, K_{VS}, nominal valve size

Given: Volume flow rate of water · Differential pressure · Density of water ρ in kg/m³

Solution: Calculate the K_V value using Equation (3) derived from Equation (1):

$$K_V = \dot{V} \cdot \sqrt{\frac{\rho}{1000 \cdot \Delta p}} \quad (3)$$

Determine the K_{VS} value from the following equation using the calculated K_V value. In general: $K_{VS} \approx 1.3 \cdot K_V$

Solution provided by Diagram 1:

For Δp = 2.1 bar and $\dot{V}$ = 12 m³/h, a K_V value of approximately 8.2 m³/h is indicated in Diagram 1.

The value for the flow velocity in the pipe can be found in Diagram 4 on page 11 using $\dot{V}$ = 12 m³/h and DN 40: $w_{pipe} \approx 2.8$ m/s

$\dot{V}$ = 12 m³/h

Δp = $p_1 - p_2$ = 2.1 bar

ρ = 1000 kg/m³

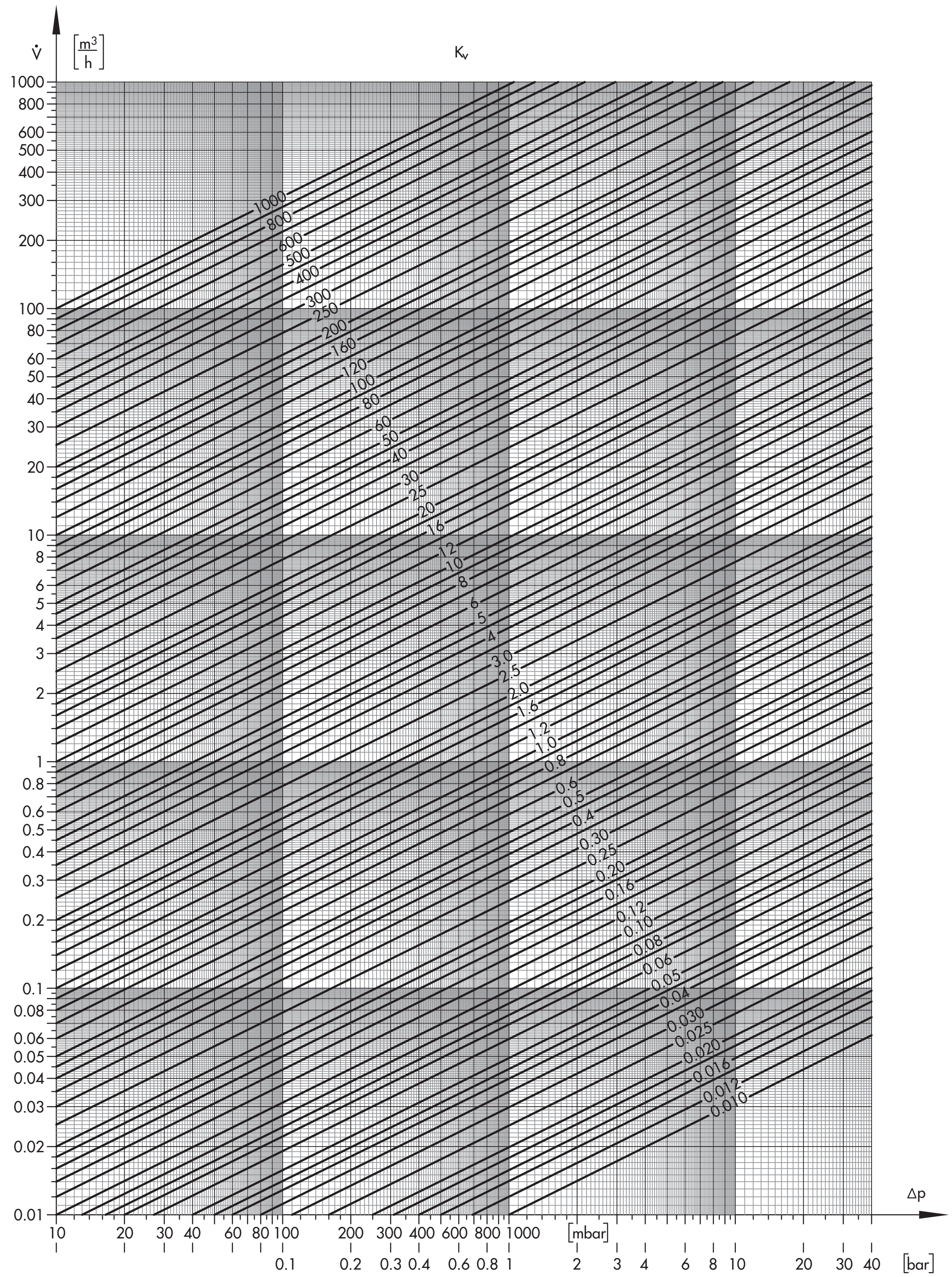
$$K_V = 12 \cdot \sqrt{\frac{1000}{1000 \cdot 2.1}} = \mathbf{8.2\ m^3/h}$$

$$K_{VS} = 1.3 \cdot K_V = 1.3 \cdot 8.2 = \mathbf{10.7\ m^3/h}$$

Selection: Type 41-23, DN 40, K_{VS} = 20

Determining S, the safety factor:

$$S = \frac{K_{VS}}{K_V} = \frac{20}{8.2} \approx 2.4$$



$\dot{V}$ in m³/h
K_V in m³/h
Δp in bar

$$\dot{V} = K_V \cdot \sqrt{\frac{1000 \cdot \Delta p}{\rho}}$$

Diagram 1 · Volume flow rate diagram for water with ρ **= 1000 kg/m³**, t = 20 °C

Sizing sample problem 4

Determine: Differential pressure $\Delta p = p_1 - p_2$ with valve fully open

Given: Type 4 Self-operated Temperature Regulator with DN 50,
$\dot{V}$, volume flow rate of water,
ρ, density of water in kg/m^3

Solution: Determine the differential pressure using Equation (4) derived from Equation (1):

$$\Delta p = \left(\frac{\dot{V}}{K_{VS}}\right)^2 \cdot \frac{\rho}{1000} \quad (4)$$

Solution provided by Diagram 1:

For $\dot{V}$ = 10 m^3/h and K_{VS} 32, a differential pressure of $\Delta p \approx 0.1$ bar is obtained from Diagram 1.

K_{VS} = 32 m^3/h
$\dot{V}$ = 10 m^3/h
ρ = 1000 kg/m^3

$$\Delta p = \left(\frac{10}{32}\right)^2 \cdot \frac{1000}{1000} = \mathbf{0.1\ bar}$$

Steam service

A modified version of Equation (8) applies to steam:

$$W = K_V \cdot m \cdot Z \qquad (5)$$

Z — The dimensionless compressibility factor Z is defined as follows: $Z = 14.2 \cdot \sqrt{p_1 \cdot \rho_1}$. Determine Z from Table 2 using the upstream pressure p_1 and differentiating between saturated steam and superheated steam.

m — Determine the dimensionless head loss coefficient m from Table 1 or, for in-between values, from Diagram 2 using (= 1.135.

Symbols and units

p_1, p_2	Absolute pressure in bar
Δp	Differential pressure in bar
W	Mass flow rate in kg/h
K_V	K_V value in m^3/h
m	Head loss coefficient, dimensionless
Z	Compressibility factor, dimensionless

Sizing sample problem 5

Determine: Steam mass flow rate in kg/h with valve fully open

Given: Type 3241-2 Electric Control Valve · Steam temperature · Upstream and downstream pressures

Solution: Calculate $\frac{p_2}{p_1}$ (convert into absolute pressure if required)

Determine m from Table 1 or Diagram 2

Determine Z from Table 2 using the upstream pressure and temperature

$$W = K_{VS} \cdot m \cdot Z \qquad (5)$$

K_{VS} = 35 m^3/h [1)]

t = 200 °C

p_1 = 4 bar p_2 = 3 bar

$\frac{p_2}{p_1} = \frac{3}{4} = 0.75$

m = 0.92

Z = 38.5

W = 35 · 0.92 · 38.5 = **1240 kg/h**

1) K_{VS} and hence also W, the calculated mass flow rate, have a tolerance of ±10 %.

Sizing sample problem 6

Determine: Type … Pressure Reducing Valve, K_{VS} value, nominal size

Given: Steam mass flow rate · Steam temperature · Upstream and downstream pressures

Solution: Calculate $\frac{p_2}{p_1}$ (convert into absolute pressure if required)

Determine m from Table 1 · Determine Z from Table 2 using the upstream pressure and temperature

Calculate K_V from Equation (6):

$$K_V = \frac{W}{Z \cdot m} \qquad (6)$$

Determine the K_{VS} value of the valve from the following equation using the calculated K_V value.

In general: $K_{VS} \approx 1.3 \cdot K_V$

W = 1000 kg/h

t = corresponds to saturated steam

p_1 = 7 bar p_2 = 2 bar

$\frac{p_2}{p_1} = \frac{2}{7} = 0.286$

m = 1

Z = 71.3

$K_V = \frac{1000}{71.3 \cdot 1} =$ **14 m^3/h**

$K_{VS} = 1.3 \cdot K_V = 1.3 \cdot 14 =$ **17.5 m^3/h**

Selection: Type 39-2, DN 40, K_{VS} = 20

Sizing sample problem 7

Determine: Differential pressure $\Delta p = p_1 - p_2$ across fully open valve

Given: Type 4 Self-operated Temperature Regulator · Steam mass flow rate · Steam temperature · Upstream pressure

Solution: Determine Z from Table 2 using the upstream pressure and temperature

$$m = \frac{W}{Z \cdot K_{VS}} \qquad (7)$$

Using m = 0.701, determine the ratio of $\frac{p_2}{p_1}$ from Diagram 2

$p_2 = 0.884 \cdot p_1 \Rightarrow$ Differential pressure $\Delta p = p_1 - p_2$

K_{VS} = 20 m^3/h

W = 1000 kg/h

t = corresponds to saturated steam

p_1 = 7 bar

Z = 71.3

$m = \frac{1000}{71.3 \cdot 20} = 0.701$

$\frac{p_2}{p_1}$ = 0.884

p_2 = 0.884 · 7 = 6.2 bar

$\Delta p = p_1 - p_2 = 7 - 6.2 =$ **0.8 bar**

Table 1 · Head loss coefficient m as a function of p_2/p_1

Pressure ratio p_2/p_1	0 to 0.6	0.70	0.75	0.80	0.85	0.90	0.95	0.99
Head loss coefficient m	1.0	0.96	0.92	0.86	0.77	0.66	0.48	0.22

Table 2 · Compressibility factor Z for steam · All pressures are indicated as absolute pressures in bar

Compressibility factor Z for ...													
p_1 in bar	**Saturated steam**	**Superheated steam** at the following temperatures ...											
		60 °C	80 °C	100 °C	120 °C	140 °C	160 °C	180 °C	200 °C	250 °C	300 °C	350 °C	400 °C
0.1	1.16	1.13	1.1	1.07	1.04	1.02	0.99	0.97	0.95	0.90	0.86	0.83	0.80
0.2	2.27	2.27	2.21	2.15	2.09	2.04	1.99	1.95	1.90	1.81	1.73	1.66	1.59
0.3	3.37		3.31	3.22	3.14	3.06	2.99	2.92	2.86	2.71	2.59	2.49	2.39
0.4	4.45		4.42	4.29	4.18	4.08	3.98	3.89	3.81	3.62	3.46	3.32	3.19
0.5	5.53			5.37	5.23	5.10	4.98	4.86	4.76	4.52	4.33	4.15	3.99
0.6	6.58			6.45	6.28	6.12	5.97	5.84	5.72	5.43	5.19	4.98	4.78
0.7	7.65			7.53	7.33	7.15	6.97	6.82	6.67	6.34	6.06	5.80	5.59
0.8	8.71			8.62	8.39	8.17	7.97	7.79	7.63	7.25	6.91	6.64	6.37
0.9	9.76			9.70	9.44	9.19	8.98	8.77	8.58	8.16	7.90	7.37	7.18
1.0	10.8			10.8	10.5	10.2	9.98	9.76	9.53	9.07	8.66	8.30	7.98
1.1	11.9				11.5	11.3	11.0	10.8	10.5	10.0	9.50	9.10	8.70
1.2	12.9				12.6	12.3	12.0	11.8	11.4	10.9	10.4	10.0	9.60
1.3	13.9				13.7	13.3	13.0	12.7	12.3	11.8	11.2	10.8	10.4
1.4	15.0				14.7	14.3	14.0	13.7	13.4	12.7	12.1	11.6	11.2
1.5	16.0				15.8	15.4	15.0	14.7	14.3	13.6	13.0	12.4	12.0
1.6	17.0				16.9	16.4	16.0	15.6	15.3	14.5	13.9	13.3	12.8
1.7	18.0				17.9	17.5	17.0	16.6	16.3	15.4	14.7	14.1	13.6
1.8	19.1				19.0	18.5	18.0	17.6	17.2	16.4	15.6	14.9	14.4
1.9	20.1				20.1	19.5	19.0	18.6	18.1	17.3	16.5	15.8	15.2
2.0	21.1				21.1	20.6	20.0	19.6	19.1	18.2	17.3	16.6	16.1
2.2	23.2					22.6	22.1	21.5	21.0	20.0	19.1	18.3	17.6
2.4	25.2					24.7	24.1	23.5	23.1	21.8	20.8	20.0	19.2
2.6	27.2					26.8	26.0	25.5	24.9	23.6	22.6	21.5	20.8
2.8	29.3					28.9	28.1	27.5	26.8	25.5	24.3	23.2	22.4
3.0	31.0					31.0	30.2	29.4	28.8	27.3	26.0	24.9	24.0
3.2	33.4					33.1	32.2	31.4	30.7	29.1	27.8	26.6	25.6
3.4	35.4					35.2	34.3	33.4	32.6	31.0	29.6	28.2	27.2
3.6	37.4					37.3	36.3	35.4	34.6	32.8	31.3	29.9	28.9
3.8	39.4						38.3	37.4	36.5	34.7	33.0	31.6	30.4
4.0	41.4						40.4	39.4	38.5	36.5	35.1	33.3	32.0
4.5	46.4						45.6	44.4	42.8	41.1	39.1	37.3	36.1
5.0	51.4						50.8	49.4	48.2	45.7	43.6	41.8	40.0
5.5	56.4						56.0	54.4	53.0	50.2	47.8	46.7	44.2
6.0	61.4						61.2	59.5	57.9	54.9	52.3	50.2	48.2
6.5	66.3							64.6	62.9	59.4	56.6	54.2	52.2
7.0	71.3							69.7	67.8	64.2	61.1	58.3	56.2
8.0	81.2							79.9	77.6	73.4	69.8	67.0	64.3
9.0	91.0							90.2	87.7	82.6	78.7	75.0	72.4
10.0	101							101	97.9	92.2	87.4	83.2	80.4
11.0	111								108	102	96.5	92.1	88.5
12.0	121								118	111	105	99.7	96.7
13.0	130								128	121	114	109	105
14.0	140								139	130	123	118	113
15.0	150								150	139	132	125	121
16.0	160									149	141	134	129
17.0	170									159	150	143	137
18.0	180									169	159	151	146
19.0	189									178	168	161	154
20.0	199									188	177	168	162
21.0	209									198	187	178	170
23.0	229									218	205	195	187
25.0	248									238	224	213	203
27.0	268									258	242	230	216
29.0	288									279	261	248	236
31.0	308									300	280	264	253
33.0	328									322	299	282	270
35.0	348									343	318	301	286
37.0	368									365	338	319	304
39.0	388									387	356	337	320
41.0	408										376	354	338

Gas service

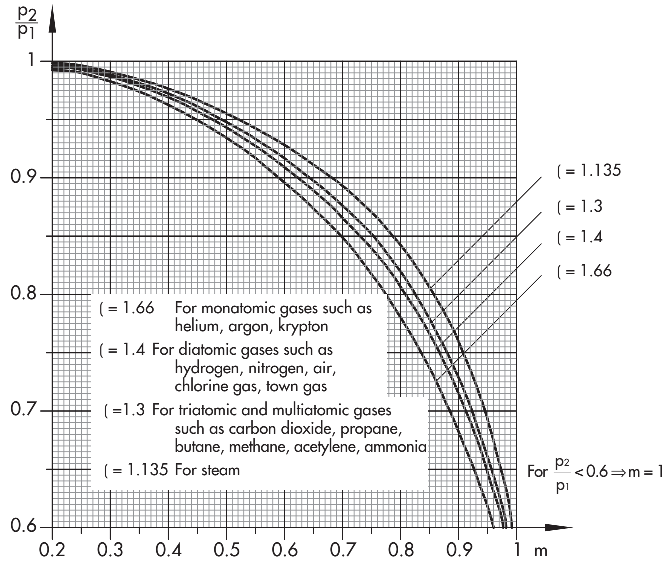


Diagram 2 · Head loss coefficient m as a function of $\frac{p_2}{p_1}$

Symbols and units

p_1, p_2	Absolute pressure in bar
Δp	Differential pressure in bar
W	Mass flow rate in kg/h
K_V	K_V value in m^3/h
ρ_1	Density in kg/m^3

The calculation procedure provides approximate values meeting practical needs.

$$W = 14.2 \cdot K_V \cdot m \cdot \sqrt{p_1 \cdot \rho_1} \qquad (8)$$

The values for m and ρ_1 can be found in Diagrams 2 and 3 respectively.

Sizing sample problem 8

Determine: Propane gas flow rate W in kg/h with valve fully open

Given: Type 3241-1 Pneumatic Control Valve, DN 50 · Upstream and downstream pressures

Solution: Determine the upstream density ρ_1 from Diagram 3

Calculate $\frac{p_2}{p_1}$ · Using $\frac{p_2}{p_1}$ and κ = 1.3, determine m from Diagram 2.

$$W = 14.2 \cdot K_{VS} \cdot m \cdot \sqrt{p_1 \cdot \rho_1} \qquad (8)$$

K_{VS} = 35 m^3/h [1)]

p_1 = 2.7 bar p_2 = 2.2 bar

ρ_1 = 5.28 kg/m^3

$\frac{p_2}{p_1} = \frac{2.2}{2.7} = 0.815$

m = 0.805

$W = 14.2 \cdot \mathbf{35} \cdot \mathbf{0.805} \cdot \sqrt{2.7 \cdot 5.28} = \mathbf{1511\ kg/h}$

1) K_{VS} and hence also W, the calculated mass flow rate, have a tolerance of ±10 %.

Sizing sample problem 9

Determine: Type … Pressure Reducing Valve, K_{VS} value, nominal size

Given: Nitrogen system · Nitrogen flow rate · Pressures p_1 and p_2

Solution: Calculate $\frac{p_2}{p_1}$ · Determine m from Diagram 2 (κ = 1.4) · Determine ρ_1 from Diagram 3 using p_1 = 5 bar

$$K_V = \frac{W}{14.2 \cdot m \cdot \sqrt{p_1 \cdot \rho_1}} \qquad (9)$$

Determine the K_{VS} value from the following equation using the calculated K_V value. In general: $K_{VS} \approx 1.3 \cdot K_V$

p_1 = 5 bar p_2 = 3 bar

W = 250 kg/h

$\frac{p_2}{p_1} = \frac{3}{5} = 0.6$

m = 0.99

ρ_1 = 6.2 kg/m^3

$K_V = \frac{250}{14.2 \cdot 0.99 \cdot \sqrt{5 \cdot 6.2}} = \mathbf{3.19\ m^3/h}$

$K_{VS} = 1.3 \cdot K_V = 1.3 \cdot 3.19 = \mathbf{3.99\ m^3/h}$

Selection: Type 44-1 Pressure Regulator, G ¾, K_{VS} = 4

Sizing sample problem 10

Determine: Differential pressure $\Delta p = p_1 - p_2$ across fully open valve

Given: Type 241-2 Electric Control Valve, DN 20 · Nitrogen system · Nitrogen flow rate · Upstream pressure

Solution: Determine ρ_1 from Diagram 3 using p_1 = 5 bar

$$m = \frac{W}{14.2 \cdot K_{VS} \cdot \sqrt{p_1 \cdot \rho_1}} \qquad (10)$$

Use m to determine $\frac{p_2}{p_1}$ from Diagram 2 $p_2 = 0.83 \cdot p_1$
$\Delta p = p_1 - p_2$

K_{VS} = 4 m^3/h

p_1 = 5 bar

W = 250 kg/h

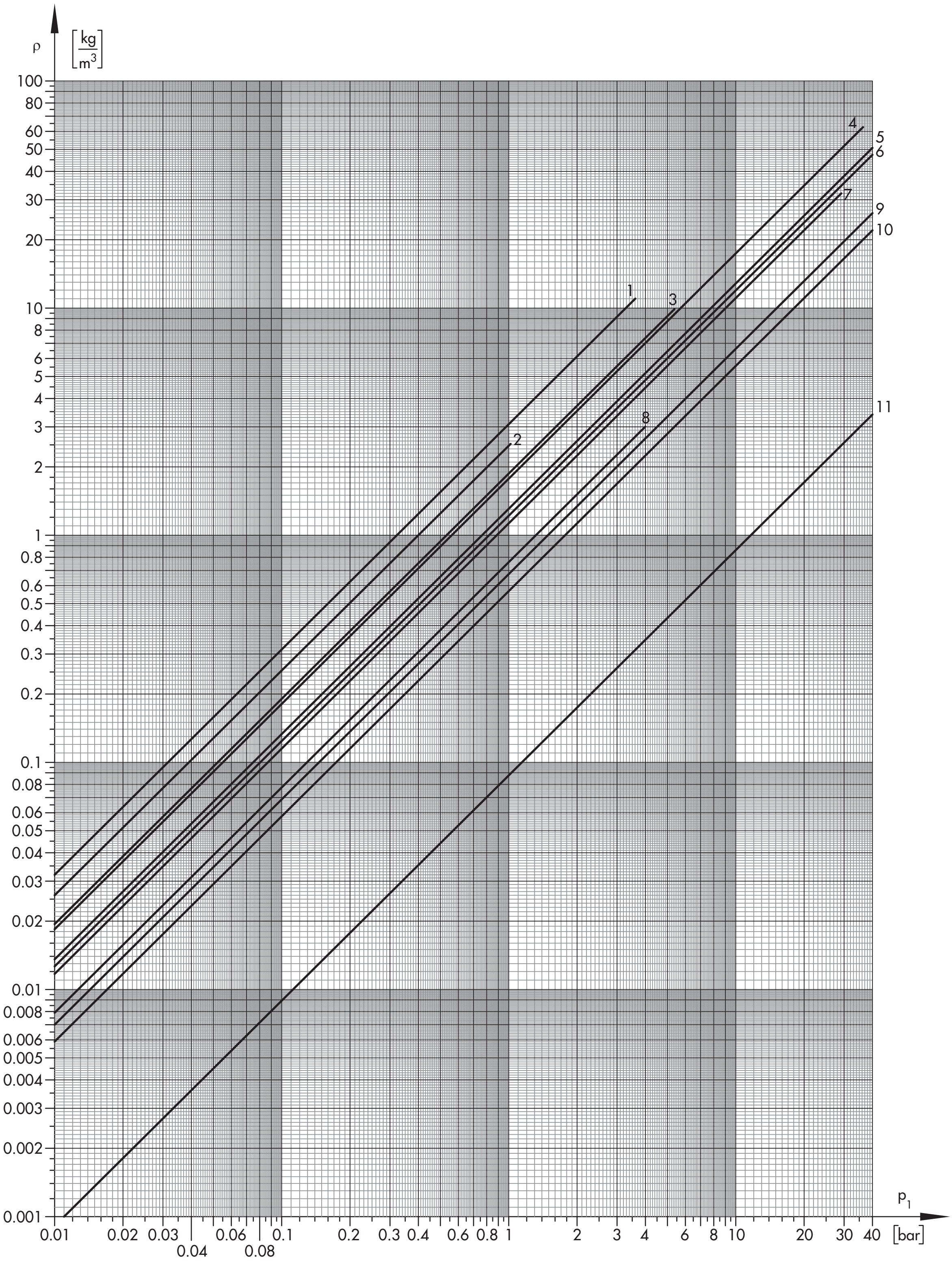
ρ_1 = 6.2 kg/m^3

$m = \frac{250}{14.2 \cdot 4 \cdot \sqrt{5 \cdot 6.2}} = \mathbf{0.791}$

$\frac{p_2}{p_1}$ = **0.83**

$p_2 = 0.83 \cdot 5 = \mathbf{4.15\ bar}$

$\Delta p = 5 - 4.15 = \mathbf{0.85\ bar}$



If the operating temperature t deviates considerably from 0 °C, correct ρ_1 using the equation $\rho_t = \rho_1 \cdot \frac{273}{273 + t}$

1	Chlorine gas
2	Butane
3	Propane
4	Carbon dioxide
5	Air
6	Nitrogen
7	Acetylene
8	Ammonia
9	Methane
10	Town gas
11	Hydrogen

Diagram 3 · Density of gases ρ or ρ_1 as a function of pressure at 0 °C

Air service

The calculation procedure provides approximate values meeting practical needs. The equation derived for dry air is as follows:

$$W = 15.3 \cdot m \cdot K_V \cdot \sqrt{p_1 \cdot \rho_1} \quad (11)$$

Equation (10) can be written as follows:

$$W = K_V \cdot m \cdot Z \quad (12)$$

The value for Z can be obtained from Table 4 using p_1. The value for m can be found in Table 3 (in-between values can be determined from Diagram 2 using (= 1.4)

Symbols and units

p_1, p_2	Absolute pressure in bar
Δp	Differential pressure in bar
W	Mass flow rate in kg/h
K_V	K_V value in m^3/h
ρ	Density in kg/m^3
m	Head loss coefficient, dimensionless
Z	Compressibility factor, dimensionless

Note:

Please contact SAMSON AG in Frankfurt/Main to obtain more detailed information on sizing flow regulators for air service.

Sizing sample problem 11

Determine: Mass flow rate in kg/h with valve fully open

Given: Type 41-23 Self-operated Pressure Regulator, DN 50 · Upstream and downstream pressures · Temperature

Solution: Calculate $\frac{p_2}{p_1}$ (convert into absolute pressure if required)

Determine the value for m from Table 3 or Diagram 2

Determine the value for Z from Table 4 using the upstream pressure and temperature

$$W = K_{VS} \cdot m \cdot Z \quad (12)$$

K_{VS} = 32 m^3/h [1)]
t = 20 °C
p_1 = 4 bar p_2 = 3 bar
$\frac{p_2}{p_1} = \frac{3}{4} = 0.75$
m = 0.884
Z = 66
W = 32 · 0.884 · 66 = **1867 kg/h**

1) K_{VS} and hence also W, the calculated mass flow rate, have a tolerance of ±10 %.

Sizing sample problem 12

Determine: Type … Pressure Reducing Valve, K_{VS} value, nominal size

Given: Upstream and downstream pressures · Temperature · Process medium is compressed air

Solution: Calculate $\frac{p_2}{p_1}$ (convert into absolute pressure if required)

Determine the value for m from Table 3 or Diagram 2 ·

Determine the value for Z from Table 4 using the upstream pressure and temperature

$$K_V = \frac{W}{Z \cdot m} \quad (13)$$

Determine the K_{VS} value from the following equation using the calculated K_V value. In general: $K_{VS} \approx 1.3 \cdot K_V$

p_1 = 5 bar p_2 = 3 bar
t = 20 °C
W = 190 kg/h
$\frac{p_2}{p_1} = \frac{3}{5} = 0.6$
m = 0.982
Z = 82.60

$K_V = \frac{190}{0.982 \cdot 82.60} = \mathbf{2.34\ m^3/h}$

$K_{VS} = 1.3 \cdot K_V = 1.3 \cdot 2.34 = \mathbf{2.93\ m^3/h}$

Selection: Type 44-1, G ½, K_{VS} = 3.2

Sizing sample problem 13

Determine: Differential pressure $\Delta p = p_1 - p_2$ across fully open valve

Given: Type 42-24 Differential Pressure Regulator, DN 50 · Flow rate of compressed air · Upstream pressure · Temperature

Solution: Determine the value for Z from Table 4 using the upstream pressure and temperature

$$m = \frac{W}{Z \cdot K_{VS}} \quad (14)$$

Determine $\frac{p_2}{p_1}$ for m = 0.884 from Diagram 2 or Table 3

$p_2 = 0.75 \cdot p_1 \Rightarrow$ Differential pressure $\Delta p = p_1 - p_2$

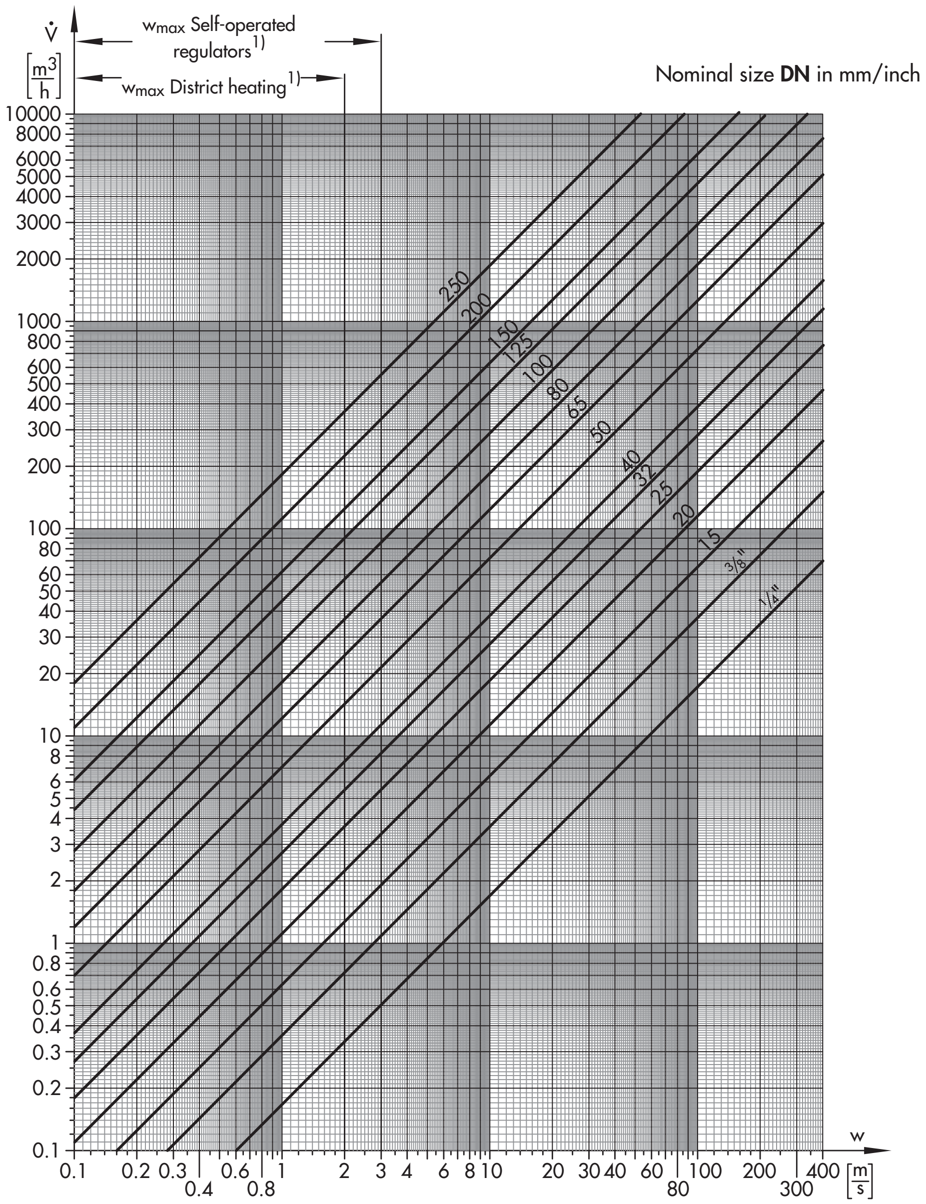
K_{VS} = 32 m^3/h
W = 3270 kg/h
t = 20 °C
p_1 = 7 bar
Z = 115.6
$m = \frac{3270}{115.6 \cdot 32} = 0.884$
$\frac{p_2}{p_1} = 0.75$
$p_2 = 0.75 \cdot 7 = 5.25$ bar
$\Delta p = p_1 - p_2 = 7 - 5.25 = \mathbf{1.75\ bar}$

Table 3 · Head loss coefficient m as a function of p_2/p_1 · All indicated pressures are absolute pressures in bar

Pressure ratio p_2/p_1	0.527	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95	0.99
Head loss coefficient m	1	0.982	0.978	0.935	0.884	0.818	0.730	0.623	0.448	0.207

Table 4 · Compressibility factor Z for air · All pressures are indicated as absolute pressures in bar

Compressibility factor Z for ...								
p_1 in bar	**Dry air** at the following temperatures ...							
	0 °C	20 °C	50 °C	100 °C	150 °C	200 °C	250 °C	300 °C
0.1	1.71	1.65	1.57	1.47	1.38	1.30	1.24	1.18
0.2	3.42	3.30	3.15	2.93	2.77	2.60	2.47	2.31
0.3	5.13	4.96	4.74	4.39	4.13	3.89	3.71	3.55
0.4	6.84	6.61	6.29	5.85	5.50	5.20	4.95	4.72
0.5	8.55	8.26	7.87	7.32	6.88	6.50	6.18	5.92
0.6	10.26	9.90	9.42	8.79	8.24	7.79	7.42	7.09
0.7	11.97	11.56	11.00	10.22	9.61	9.09	8.64	8.27
0.8	13.68	13.22	12.58	11.72	11.00	10.40	9.79	9.45
0.9	15.40	14.86	14.15	13.18	12.36	11.69	11.12	10.62
1.0	17.10	16.50	15.72	14.65	13.75	13.00	12.35	11.81
1.1	18.83	18.15	17.30	16.07	15.10	14.32	13.60	13.00
1.2	20.50	19.80	18.20	17.52	16.50	15.60	14.70	14.12
1.3	22.10	21.42	20.45	18.25	17.85	16.90	16.09	15.35
1.4	24.00	23.10	22.00	10.70	19.25	18.19	17.30	16.55
1.5	25.65	24.75	23.60	21.68	20.06	19.46	18.55	17.70
1.6	27.30	26.40	25.15	23.35	21.95	20.80	19.78	18.88
1.7	29.10	28.10	26.70	24.80	23.40	22.05	20.90	20.10
1.8	30.80	29.70	28.30	26.35	24.75	23.35	22.25	21.20
1.9	32.25	30.25	29.60	27.55	26.15	24.65	23.50	22.50
2.0	34.20	33.00	31.45	29.27	27.70	25.95	24.70	23.10
2.2	37.65	36.40	34.70	32.20	30.20	28.50	27.20	25.90
2.4	41.10	39.60	37.75	35.15	33.30	31.20	29.70	28.35
2.5	42.70	41.40	39.30	36.60	34.40	32.45	30.90	29.50
2.6	44.50	42.60	40.90	38.05	35.75	33.80	32.15	30.70
2.8	47.80	46.20	44.00	41.70	38.45	36.35	34.55	33.10
3.0	51.30	49.55	47.40	43.95	41.25	38.90	37.10	35.45
3.2	54.30	52.40	49.90	46.60	43.90	41.60	39.80	37.70
3.4	58.25	56.20	53.50	49.80	46.70	44.20	42.00	40.10
3.6	62.20	59.60	56.60	52.70	49.40	46.80	44.50	42.60
3.8	65.00	62.70	59.75	55.60	51.50	49.40	46.90	44.80
4.0	68.20	66.00	62.90	58.55	55.00	52.00	49.40	47.20
4.5	77.00	74.40	70.70	65.80	61.80	58.50	55.60	48.50
5.0	86.90	82.60	78.75	73.20	68.75	65.00	61.75	59.20
5.5	94.00	90.90	87.40	80.60	75.60	71.60	68.00	64.90
6.0	102.06	98.90	94.30	87.90	82.40	77.90	74.15	70.90
6.5	111.0	107.2	101.10	95.20	88.40	84.50	80.40	76.80
7.0	119.6	115.6	110.0	102.2	96.90	90.90	86.40	82.70
8.0	136.8	132.2	125.7	117.1	110.0	104.0	97.9	94.5
9.0	162.2	148.6	141.6	131.8	123.6	116.9	111.2	106.2
10.0	171.0	165.0	157.2	146.5	137.5	130.0	123.5	118.1
11.0	188.3	181.5	173.0	160.7	151.0	143.2	136.0	130.0
12.0	205.0	198.0	182.0	175.2	165.0	156.0	147.0	141.0
13.0	221.0	214.2	204.5	182.5	178.5	169.0	160.9	153.5
14.0	240.0	231.0	220.0	197.0	192.5	181.9	173.0	165.5
15.0	256.5	247.5	236.0	216.8	200.6	194.6	185.5	177.0
16.0	273.0	264.0	251.0	253.5	219.5	208.0	197.8	188.8
17.0	291.0	281.0	267.0	248.0	234.0	220.5	209.0	201.0
18.0	308.0	297.0	283.0	263.5	247.5	233.5	222.5	212.0
19.0	322.5	302.5	296.0	275.6	261.6	246.5	235.0	225.0
20.0	342.0	330.0	314.5	292.7	277.0	259.6	247.0	231.0
22.0	376.5	364.0	347.0	322.0	302.0	285.0	272.0	259.0
24.0	411.0	395.0	377.5	351.5	333.0	312.0	297.0	283.5
26.0	445.0	428.0	409.0	380.5	357.5	338.5	321.5	307.0
28.0	478.0	462.0	440.0	417.0	384.5	363.5	345.5	331.0
30.0	513.0	495.5	474.0	439.5	412.5	389.0	371.0	354.5



1) Only for water

Diagram 4 · V̇ – w diagram for gases, steam and liquids

Diagram 4 shows the following relationship:

$$\dot{V}_{pipe} = A_{pipe} \cdot w_{pipe} \qquad (15)$$

$\dot{V}_{pipe}$ Volume flow rate in m^3/h
w_{pipe} Flow velocity in m/s
A_{pipe} Cross-sectional area of the assumed nominal size plotted as a straight line
DN Nominal size

Determining velocity and nominal size
Velocity w of the medium

$$w_{pipe} = \dot{V}_{pipe} \cdot \left(\frac{18.8}{DN}\right)^2 \qquad (16)$$

Nominal size DN

$$DN = 18.8 \cdot \sqrt{\frac{\dot{V}}{w_{pipe}}} \qquad (17)$$

For gas service, the flow rate determined from Diagram 4 in **m^3/h** can be converted into **kg/h** or **m^3/h** for the normal condition (refer to sizing sample problem 14).

$\dot{V}_G$ Gas flow rate, based on normal condition

Sizing sample problem 14

Determine: Flow rates of compressed air for operating and normal conditions

Given: Pipe diameter · Pressure p in the pipe · Flow velocity

Solution: Volume flow rate in m^3/h for the operating condition can be obtained from Diagram 4 using DN 32 and w_{pipe}. Determine ρ from Diagram 3 using p.
Calculate the mass flow rate of the compressed air in kg/h.

$$W = \dot{V} \cdot \rho \qquad (18)$$

$\dot{V}_G$ is the volume flow rate of gas in m^3/h for normal condition at 0 °C and 1013 mbar. Determine $\dot{V}_G$ according to the equation to the right.

Nominal size = DN 32

p = 5 bar

w_{pipe} = 7 m/s

$\dot{V}$ = 20 m^3/h

From Diagram 3:

ρ = 6.3 kg/m^3

W = 20 · 6.3 = **126 kg/h**

Normal condition:

1 m^3 of air ⇒ 1.293 kg

$$\dot{V}_G = \frac{W}{1.293} = \frac{126}{1.293} = \mathbf{97.5\ m^3/h}$$

Specifications subject to change without notice.

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