Flow data, flow factor and orifice size

Importance of properly sizing valves

It is important to properly size a valve. There are undesirable effects in both undersizing and oversizing.

Undersizing may result in:

1) the inability to meet desired flow requirements
2) the flashing of liquids to vapours on the outlet side of the valve
3) a fall in the outlet pressure
4) substantial pressure losses in the piping system

Oversizing may result in:

1) unnecessary cost of oversized equipment
2) variable flow through the valve or erratic control of the flow
3) shorter life of some valve designs through oscillating of internal parts to maintain required internal pressure differentials, caused by lack of flow
4) erratic operation of some designs such as failure to shift position due to lack of required flow in 3- and 4-way valves
5) erosion or wire drawing of seats in some designs because they operate in the nearly closed position

Definition of Kv

The flow coefficient Kv in cubic metres per hour or litres per minute is a special volumetric flow rate (capacity) through a valve at a specified travel and at the following conditions:

- the static pressure loss (Δp_{Kv}) across the valve is 10^5 Pa (1 bar)
- the fluid is water within a temperature range of 278 K to 313 K (5°C to 40°C)
- the unit of the volumetric flow rate is cubic metre per hour or litres per minute

The Kv value can be obtained from test results with the help of the following equation:

$$Kv = Q\sqrt{\frac{\Delta p_{Kv} \cdot \rho}{\Delta p \cdot \rho_w}}$$

where:

Q is the measured volumetric flow rate in cubic metres per hour or litres per minute

Δp_{Kv} is the static pressure loss of 10^5 Pa (see above)

Δp is the measured static pressure loss across the valve in pascals

ρ is the density of the fluid in kilograms per cubic metre

ρw is the density of water (see above) in kilograms per cubic metre (according to IEC 534)

Conditions to be known

In general, we must know as many of the conditions surrounding the application as possible.

Flow required in cubic metres per hour (m^3/h) for liquids, normal cubic metres per hour (nm^3/h) for gases, or kilograms per hour (kg/h) for steam. These figures can be obtained by simply asking the customer's requirements or referring to the nameplates on pumping equipment, boiler room charts or calculations.

Inlet Pressure (p_1) - This is usually obtained from the source of the supply or by placing a pressure gauge near the valve inlet.

Outlet Pressure (p_2) - This can be obtained by gauge observations, but usually is tied in with specifications regarding allowable system pressure drop. If we know the inlet pressure and the pressure drop, then the outlet pressure is easy to determine.

Pressure Drop (Δp) - In large or complicated systems, it is desirable to keep the pressure drop across a valve to a minimum, and often the customer will have definite specifications concerning the factor. Of course, if the valve is discharging to atmosphere, the pressure drop is equal to the inlet pressure when dealing with liquids. However, when sizing valves for use with gases and steam, although the valve may be discharging to atmosphere, only 50 percent of the inlet pressure can be used for the pressure drop used in the formulas (commonly called critical pressure drop). In all other cases, the pressure drop is the difference between inlet and outlet pressures.

Note: It is often difficult to understand the meaning of the term "minimum operating pressure differential" (see page V045).

Certain pilot operated valves function by differential pressures created internally by "pilot" and "bleed" arrangements. This differential is measured as the difference between inlet and outlet conditions on all valve construction. If pressure conditions are not known, but only flow information, we can use the graphs or formulas to solve the resulting pressure drop.

If the drop is less than assigned minimum differential, the valve is oversized. In these situations, a valve with a lower minimum operating pressure differential should be employed or, alternatively, a smaller sized valve with a more closely defined Kv factor.

The formulas necessary to determine the Kv are quite complicated and for that reason a series of flow graphs was developed which reduce that problem to one of a simple multiplication or division.

All flow calculations for a fluid have been simplified to a basic formula:

$$Kv = \frac{\textbf{Flow required: Q}}{\textbf{Graph factors: } F_{gm}, F_{sg}, F_{gl}}$$

The graph factors F_{gm}, F_{sg}, F_{gl} can be easily picked out by aligning known pressure conditions on the graphs I to X on the following pages (for calculations see next page).

The tables below can be used to estimate a Kv if the orifice size is known, or to relate the approximate orifice size if the Kv is known. The chart is based on the ASCO design of in-line globe type valves. The flow charts must be used for precise sizing and converting Kv factors to actual flow terms, and the catalogue page must be consulted for the actual Kv of a particular valve.

Approx. orifice size	approx. Kv	
(mm)	(m^3/h)	(l/min)
0,8	0,02	0,33
1,2	0,05	0,83
1,6	0,08	1,33
2,4	0,17	2,83
3,2	0,26	4,33
3,6	0,31	5,17
4,8	0,45	7,50
6,4	0,60	10,0
8	1,5	25,0
9	1,7	28,3

Approx. orifice size	approx. Kv	
(mm)	(m^3/h)	(l/min)
13	3	50,0
16	4	66,7
18	4,5	75,0
19	6,5	108
25	11	183
32	15	250
38	22	366
51	41	683
64	51	850
76	86	1433
80	99	1650
100	150	2500
125	264	4400
150	383	6375

SAMPLE PROBLEMS

LIQUIDS (Tables I and III)

To find Kv: What Kv is required to pass 22 litres of oil per minute with a specific gravity of 0,9 and a pressure drop of 1,5 bar?

The viscosity is less than 9° Engler.

Solution: The formula is:

$$Kv\ (m^3/h) = \frac{Q\ (m^3/h)}{F_{gm}\ .\ F_{sg}}$$

$$Kv\ (l/min) = \frac{Q\ (m^3/h)}{F_{gl}\ .\ F_{sg}}$$

To find Fg, use the Liquid Flow Graph.

The Fgm factor is that corresponding to a pressure drop of 1,5 bar and equals 1,25.
The Fgl factor is 0,075.

The Fsg factor can be obtained from the Fsg chart and is that corresponding to 0,09 specific gravity and equals 1,05.

Therefore:

$$Kv = \frac{60.22.10^{-3}}{1,25.1,05} = 1\ m^3/h$$

$$Kv = \frac{60.22.10^{-3}}{0,075.1,05} = 16,7\ l/min$$

AIR AND GASES (Tables I and IV - VII)

To find Kv: A valve is required to pass 14 nm³/h at an inlet pressure of 4 bar and a pressure drop (Δp) of 0,5 bar.
Find the Kv if the fluid is carbon dioxide.

Solution: Refer to the 1-10 bar graph.
The formula used is:

$$Kv\ (Nm^3/h) = \frac{Q\ (Nm^3/h)}{F_{gm}\ .\ F_{sg}}$$

$$Kv\ (Nl/min) = \frac{Q\ (Nm^3/h)}{F_{gl}\ .\ F_{sg}}$$

Locate Fgm at the intersection of 4 bar inlet pressure and 0,5 bar pressure drop Δp (along curve). Read down to Fgm = 43,5.
Fgl factor is 2,61.

Locate Fsg corresponding to specific gravity of carbon dioxide (= 1,5) on Fsg Chart.
Fsg = 0,81

Insert values into formula:

$$Kv = \frac{Q\ (Nm^3/h)}{F_{gm}\ .\ F_{sg}} = \frac{14}{43,5.0,81} = 0,4\ Nm^3/h$$

$$Kv = \frac{Q\ (Nm^3/h)}{F_{gl}\ .\ F_{sg}} = \frac{14}{2,61.0,81} = 6,62\ Nl/min$$

STEAM (Tables VIII - X)

To find Kv: A valve is required to pass 25 kg/h of saturated steam at an inlet pressure of 1 bar and a Δp of 0,2 bar.
What is the Kv?

Solution: Refer to the appropriate Steam Graph.
Use the formula:

$$Kv\ (m^3/h) = \frac{Q\ (kg/h)}{F_{gm}}$$

$$Kv\ (l/min) = \frac{Q\ (kg/h)}{F_{gl}}$$

Locate Fg on graph corresponding to 1 bar inlet pressure and a Δp of 0,2 bar (along curve).
Fgm = 13,8 and the Fgl = 0,83

Insert values into formula:

$$Kv = \frac{Q\ (kg/h)}{F_{gm}} = \frac{25}{13,8} = 1,8\ m^3/h$$

$$Kv = \frac{Q\ (kg/h)}{F_{gl}} = \frac{25}{0,83} = 30\ l/min$$

Formula for liquid

$$Kv = Q\ .\ \sqrt{\frac{(S.G.)}{\Delta p\ .\ 1000}}$$

$$Q = Kv\ .\ \sqrt{\frac{\Delta p\ .\ 1000}{(S.G.)}}$$

$$\Delta p = (S.G.)\ .\ \left(\frac{Q}{Kv}\right)^2 .\ \frac{1}{1000}$$

Formula for gases (with temperature correction) (1)

$p_2 < \frac{p_1}{2}$

$$Kv = \frac{Q_N}{257.\ p_1}\ .\ \sqrt{(S.G.)_N\ .\ T_1}$$

$$Q_N = 257\ .\ Kv\ .\ p_1\ .\ \frac{1}{\sqrt{(S.G.)_N\ .\ T_1}}$$

$$\Delta p \neq f\ (Kv\ ,\ Q_N\ ,\ (S.G.)_N\ ,\ p_2\ ,\ T_1)$$

$p_2 \geqslant \frac{p_1}{2}$

$$Kv = \frac{Q_N}{514}\ .\ \sqrt{\frac{(S.G.)_N\ .\ T_1}{\Delta p\ .\ p_2}}$$

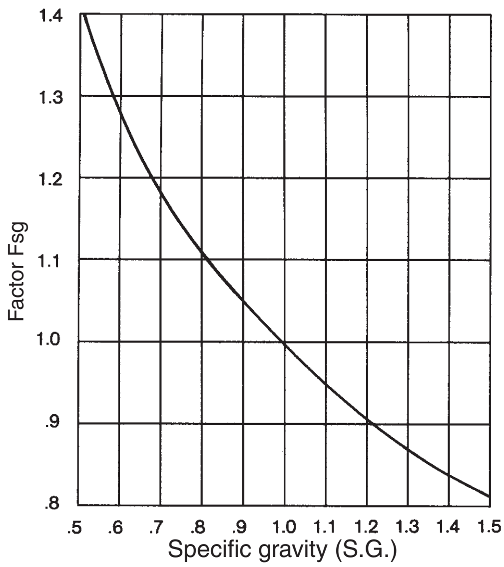
$$Q_N = 514\ .\ Kv\ .\ \sqrt{\frac{\Delta p\ .\ p_2}{(S.G.)_N\ .\ T_1}}$$

$$\Delta p = \frac{Q_N^2\ .\ (S.G.)_N\ .\ T_1}{Kv^2\ .\ 514^2\ .\ p_2}$$

(S.G.)	(kg/m³)	: specific gravity related to water for liquids
(S.G.)N	(kg/m³)	: specific gravity related to air for gases
T_1	(°C)	: fluid temperature at the valve inlet
T_2	(°C)	: fluid temperature downstream of the valve
Q	(m³/h)	: flow
Q_N	(Nm³/h)	: volumetric flow across the valve
Kv	(m³/h)	: flow coefficient
p_1	(bar)	: pressure at the valve inlet
p_2	(bar)	: pressure downstream of the valve
Δp	(bar)	: pressure drop

(1) To calculate the volumetric flow **Q_N** we must know:
- the **Kv** coefficient
- the specific gravity **(S.G.)N** of the fluid
- the pressure loss **Δp** across the valve
- the fluid pressure **p_2** downstream of the valve
- the fluid temperature **T_1** at the valve inlet

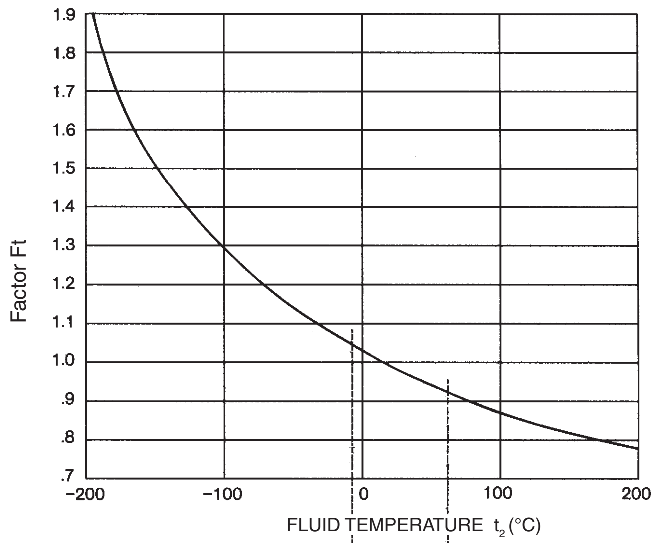
Table I : Calculation factor Fsg



OTHER GRAVITIES

$$Fsg = \frac{1}{\sqrt{S.G.}}$$ specific gravity (for 1 bar absolute and 15°C)

Table II : Calculation factor Ft for temperature correction



OTHER TEMPERATURES

$$Ft = \sqrt{\frac{293}{273° + t_2}}$$

The correction for temperature in the range of -7°C to 65°C is very small and, therefore, can be ignored in ordinary applications

Table III : Flow calculation Fgm and Fgl for liquids

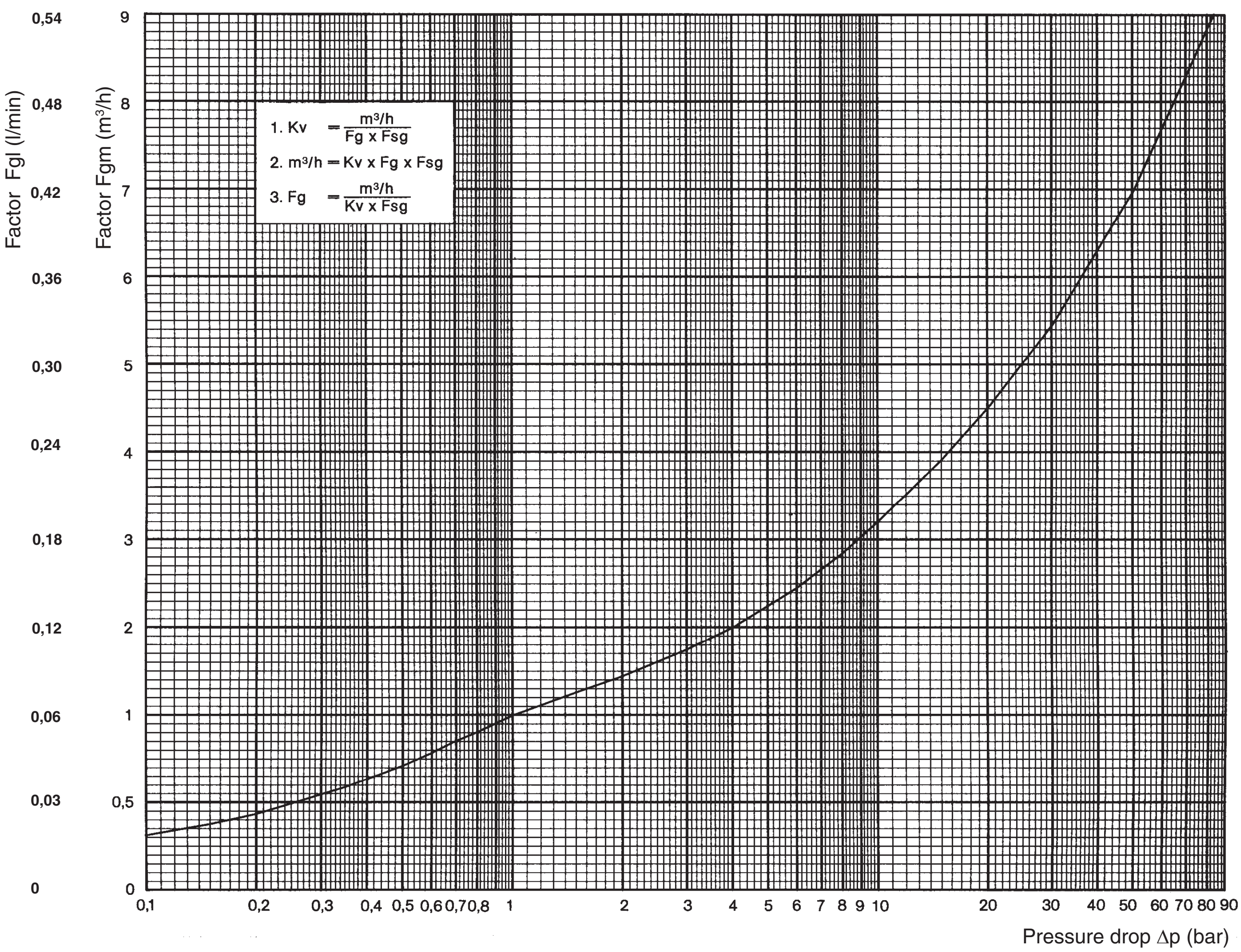


Table IV : Flow calculation Fgm and Fgl for air/gas

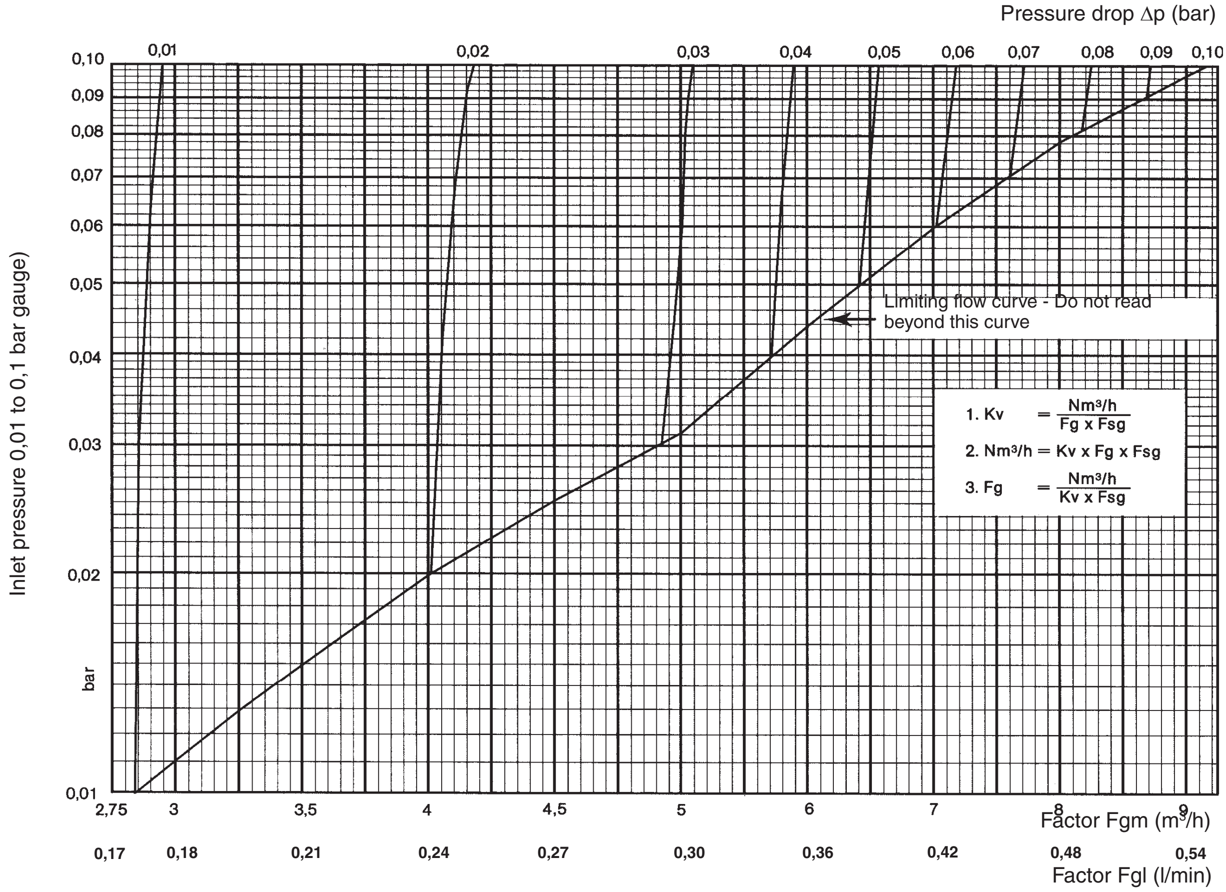


Table V : Flow calculation Fgm and Fgl for air/gas

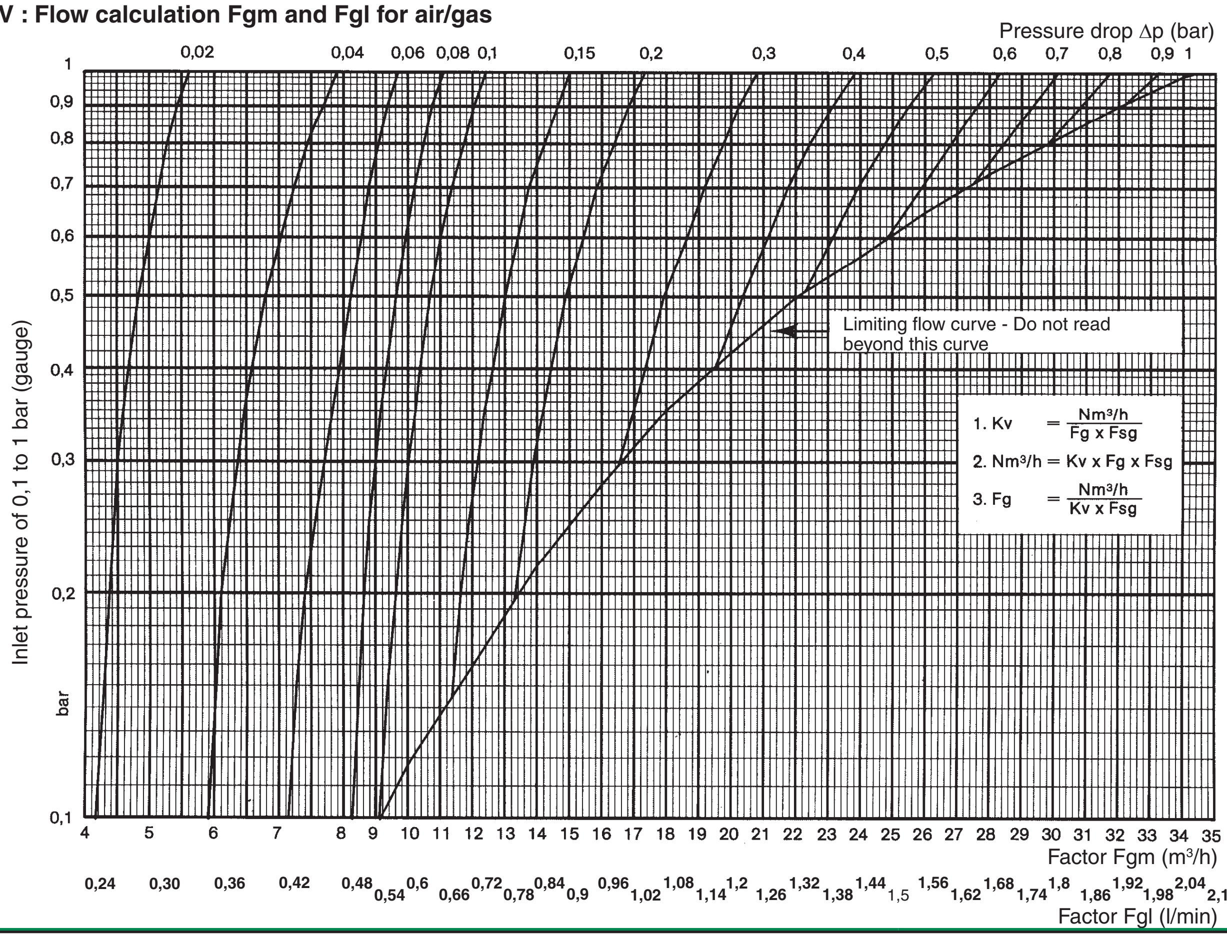


Table VI : Flow calculation Fgm and Fgl for air/gas

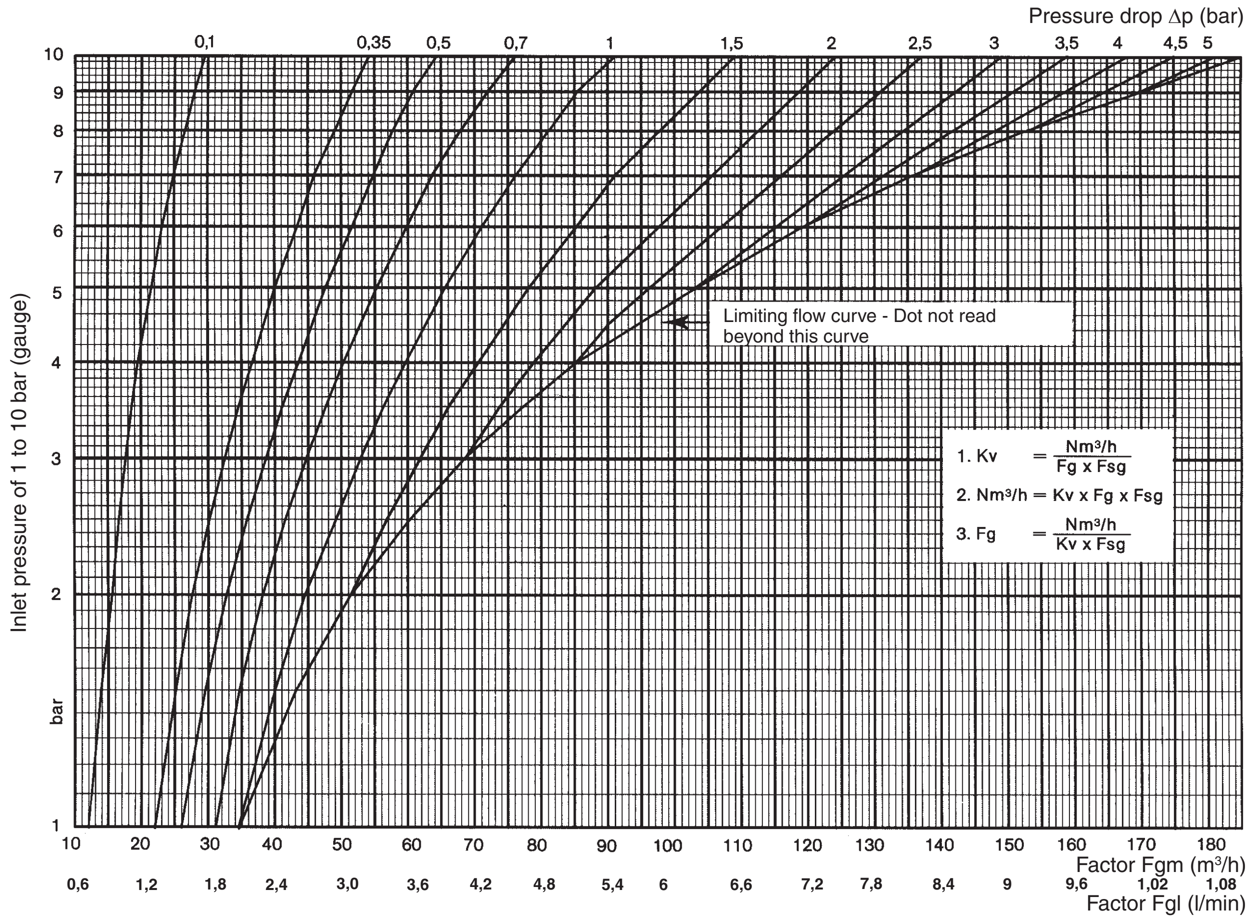


Table VII : Flow calculation Fgm and Fgl for air/gas

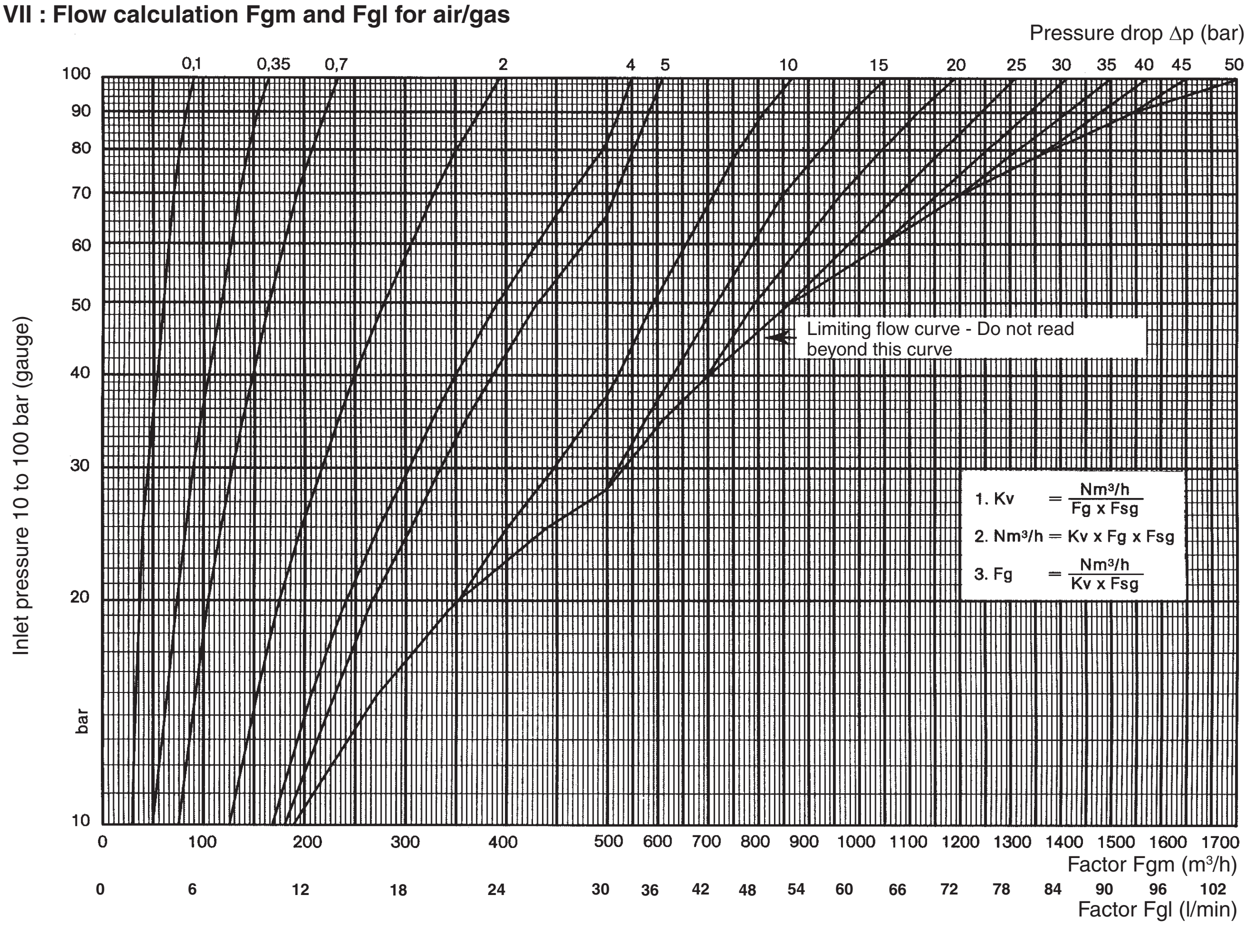


Table VIII : Flow calculation Fgm and Fgl for steam

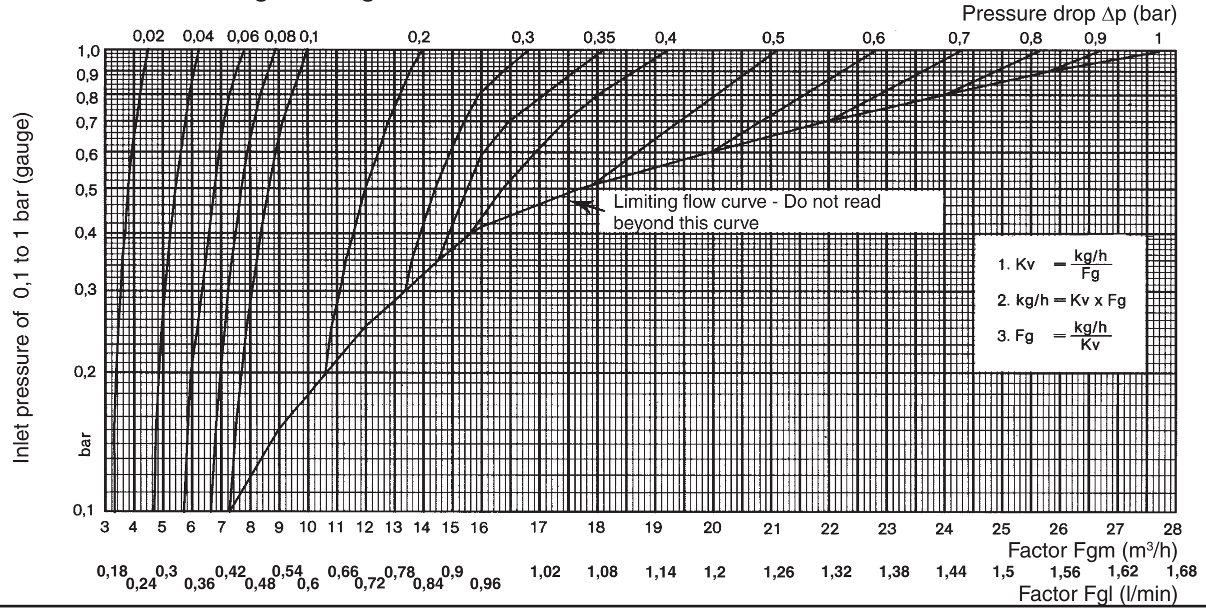


Table IX : Flow calculation Fgm and Fgl for steam

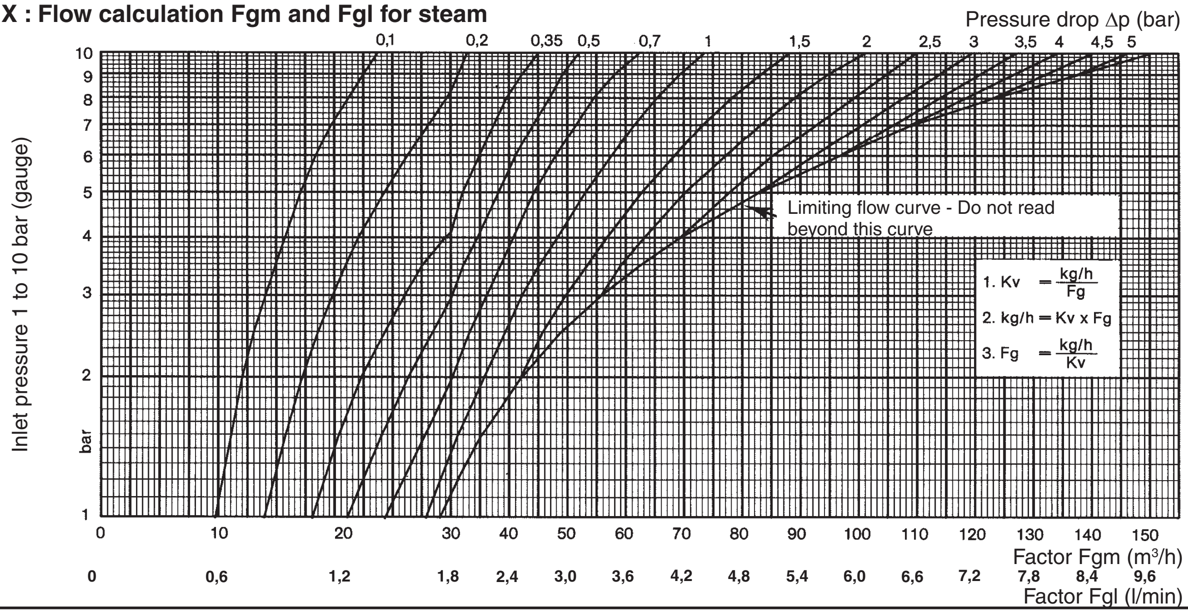
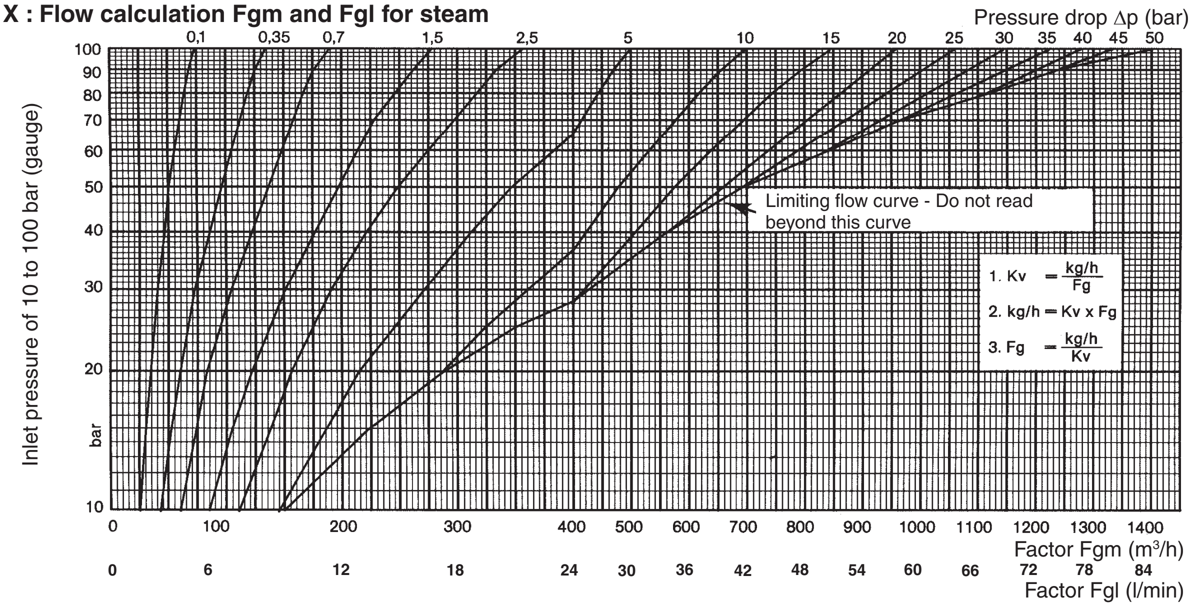


Table X : Flow calculation Fgm and Fgl for steam



All leaflets are available on: **www.asco.com**

ADDITIONAL FLOW FORMULAS AND PHYSICAL DATA

Definition of Kv (or Cv) coefficient

Valve flow coefficient Kv (or Cv) is the flow of water (specific gravity = 1), expressed in volume unit "A" per time unit "B", that will pass through a valve at a pressure drop equal to pressure unit "C" (see table below).

Kv and Cv conversion table

units		symbol	conversion formulas
volume "A"/ time "B"	pressure "C"		
l / min	bar	Kv	1 Kv = 0,06 Kvh = 0,05 Cve = 0,07 Cv
m^3 / h	bar	Kvh	1 Kvh = 16,7 Kv = 0,97 Cve = 1,17 Cv
gallon GB (Imp. gallon) / min	psi	Cve	1 Cve = 17,1 Kv = 1,03 Kvh = 1,2 Cv
gallon US / min	psi	Cv	1 Cv = 14,3 Kv = 0,85 Kvh = 0,83 Cve

Flow calculation

General: Pressure drop values for which no curves are shown, may be determined by interpolation in the graphs. However, more accurate results can be obtained for the calculation of the required values by using the following equations (on which the flow graphs are based):

p_1 = absolute inlet pressure (bar) = gauge pressure plus atmospheric pressure of 1,013 bar

p_2 = absolute outlet pressure (bar) = gauge pressure plus atmospheric pressure of 1,013 bar

Δp = p_1 - p_2 = pressure drop across the valve (bar)

t = 0°C

Note: In most systems it is desirable to keep the pressure drop to a minimum. If necessary - in case of liquids - the pressure drop may equal the total inlet (gauge) pressure. This also applies to air, gases and steam up to 1,013 bar inlet (gauge) pressure but for these fluids never use a Δp greater than 50% of the absolute inlet pressure because excessive pressure drops will cause an irregular flow. If Δp is not specified and this information is needed to size the valve, a rule of thumb is to take 10% of the inlet pressure as pressure drop.

Liquids

$$F_{gm} = \sqrt{\Delta p} \quad (m^3/h)$$

and

$$F_{gl} = 0,06\sqrt{\Delta p} \quad (l/min)$$

Example: For Δp = 1,7 bar, Fgm = 1,3 (m^3/h) and Fgl = 0,08 (l/min) will be found.

Note: If the fluid viscosity is higher than 300 SSU (approx. 9°E), the determined Kv-value must be adjusted. Contact us.

Air and gases

$$F_{gm} = 18,9\sqrt{\Delta p\ (2p_1 - \Delta p)} \quad (m^3/h)$$

$$F_{gl} = 1,13\sqrt{\Delta p\ (2p_1 - \Delta p)} \quad (l/min)$$

Example: Δp = 0,4 bar;
p_1 = 3 bar gauge or
4,013 bar absolute.

Calculation:

$$F_{gm} = 18,9\sqrt{0,4(8,026 - 0,4)} = 33 \quad m^3/h$$

$$F_{gl} = 1,13\sqrt{0,4(8,026 - 0,4)} = 1,97 \quad l/min$$

Note: The gas equations only apply accurately to a fluid temperature of 20°C (for the purpose of this catalogue, the standard cubic metre nm^3 has been defined at 20°C and 1,013 bar absolute or 760 mm mercury). At a different temperature (= t_2 °C) the determined Kv_1 value must be adjusted by the following correction factor.

$$F_t = \sqrt{\frac{293}{273 + t_2}}$$

Specific gravity of various liquids at 20°C (related to water at 4°C)

Alcohol, Ethyl	0,79
Bezene	0,88
Carbon tetrachloride	1,589
Castor Oil	0,95
Fuel Oil no. 1	0,83
Fuel Oil no. 2	0,84
Fuel Oil no. 3	0,89
Fuel Oil no. 4	0,91
Fuel Oil no. 5	0,95
Fuel Oil no. 6	0,99
Gasoline (petrol)	0,75 to 0,78
Glycerine	1,26
Linseed Oil	0,94
Olive Oil	0,98
Turpentine	0,862
Water	1,000

The actual flow factor is: $Kv_2 = \frac{Kv_1}{F_t}$

Steam and vapours (e.g. refrigerants)

For steam:

$$F_{gm} = 15,83\sqrt{\Delta p(2P_1 - \Delta P)} \quad (m^3/h)$$

$$F_{gl} = 0,95\sqrt{\Delta p(2P_1 - \Delta P)} \quad (l/min)$$

Example: Δp = 7 bar,
p_1 = 40 bar or
41,013 bar abs.

Calculation:

$$F_{gm} = 15,83\sqrt{7(82,026 - 7)} = 363 \quad m^3/h$$

$$F_{gl} = 0,95\sqrt{7(82,026 - 7)} = 21,8 \quad l/min$$

Note 1: The steam formulas apply to saturated steam. For superheated steam a correction factor is required. Contact ASCO.

Note 2: For vapours, e.g. chlorofluorocarbons (CFCs), various other factors have to be considered.

Specific gravity of various gases (at 20°C and atm. pressure and related to air)

Acetylene	0,91
Air	1,000
Ammonia	0,596
Butane	2,067
Carbon dioxide	1,53
Chloride	2,486
Ethane	1,05
Ethyl chloride	2,26
Helium	0,138
Methane	0,554
Methyl chloride	1,785
Nitrogen	0,971
Oxygen	1,105
Propane	1,56
Sulphur dioxide	2,264

FLOW COEFFICIENTS

. **C** and **b** (following standard ISO 6358) :
Coefficients C (sonic conductance) and b (critical pressure ratio) following standard ISO 6358 allow flow calculation under sonic conditions (See solenoid pilot valves 195/LISC - section I).

$$\mathbf{C} = \frac{q^*_m}{\rho_o p_1}$$

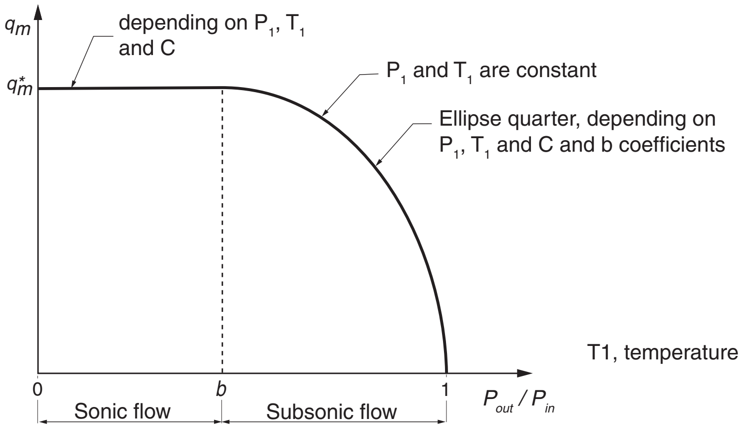
$$\mathbf{C} = \frac{q^*_v}{p_1}$$

q^*: mass flow rate q^*_m (kg/s) or volume q^*_v (m^3/s) through a component at sonic flow
p_1: inlet pressure (bar)
ρ_o = 1,3 kg/m^3 : density under standard conditions (p_0 = 1 bar, T_0 = 293,15 K and 65% relative humidity)

b : pressure ratio below which the flow is sonic:

$$\mathbf{b} = \frac{P_2}{P_1}$$

P_2: outlet pressure (bar)
P_1: inlet pressure (bar)



T1, temperature (°K) measured when the flow is sonic

CALCULATION OF FLOW (for air and gas)

. **Defining flow at 6 bar:**
The corresponding leaflets give for each product its mean flow in litres per minute at 6 bar at a standard reference atmosphere (ANR) conforming to ISO 8778 (**with Δ P = 1 bar**)

. **Calculation of flow:**

$\Delta P < P$ inlet /2

$$Q = 28{,}16 \times Kv \times \sqrt{\Delta P \times P_{in}}$$

including correction for temperature and density

$$Q = 475 \times Kv \times \sqrt{\frac{(\Delta P \times P_{in})}{(T_a \times d)}}$$

$\Delta P \geq P$ inlet /2
(Maximum allowable flow)

$$Q = 14 \times Kv \times P_{out}$$

including correction for temperature and density

$$Q = 238{,}33 \times Kv \times P_{out} \times \frac{1}{\sqrt{(T_a \times d)}}$$

Q = Flow in l/min
ΔP = Differential pressure, in bar
P_{in} = Absolute inlet pressure, in bar
P_{out} = Absolute outlet pressure, in bar
T_a = Absolute temperature, in Celsius degrees
d = Density compared with air