2008-09-18

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Diagrams and nomograms for the Flowtec Handbook

These diagrams and nomograms were developed by Klaus Daube in 2003 for E+H Flowtec AG, CH-4153 Reinach near Basel. Hence they are copyrighted and must not be used in a commercial environment, that is, may not be used in any sold publication.

If you use these diagrams and nomograms you are required to provide the source information:

English	Flow Handbook, 2nd Edition 2004, completely revised, ISBN 3-9520220-4-7
Deutsch	Durchfluss Handbuch, 4. Auflage 2003, volständig überarbeitet, ISBN 3-9520220-3-9

Note: *This text is the development documentation of the diagrams. Comments indicate some discussion between the author and the contractor due to ambiguities and errors in the old diagrams.*

The size of the diagrams fit into the A5 sized book. Thanks to PDF the new diagrams can be printed in any size.

Diagram overview

Introductory remarks

Sources of data and information

[Çengel] Yunus A. Çengel, Robert H. Turner: Fundamentals of Thermal-Fluid Sciences [McGraw-Hill 2001] ISBN 0-07-118152-0.

[Crane] Crane Technical Paper No 410, New York 1991

This TP is the quintessential guide to understanding the flow of fluid through valves, pipes and fittings, enabling you to select the correct equipment for your piping system.

Originally developed in 1942, the latest edition of Crane TP-410 serves as an indispensable technical resource for specifying engineers, designers and engineering students.

TP-410 is published by Crane Valve Group (CVG), one of the world's leading suppliers of valve products and services.

It is, for example, available at shops.flowoffluids.com (2008: USD 45.-)

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(e-mail correspondence with the author 2002-12).

[Vogel] Chemiker Kalender, Edited by H.U. v. Vogel, [Springer 1956]

[web1] http://homepages.compuserve.de/ctmattke/viskos1.html as of 2002-12

[PressureDrop] This program from software-factory.de (current version 2008 is 6.2) is available both in German and English. The web site also provides an online-calculator.

The dilemma of the nominal diameter

A basic problem in most of the diagrams is the incompatibility of nominal diameter and inner diameter of a pipe. Hence the cross section area is not correct if DN = D_i is assumed.

Steep pipes according to DIN 2448:

DN [mm]	10	50	100	200
D_i [mm]	13.6	54.5	107.1	207.3
Cross section [a]	1.85	29.7	114.7	430
Error in %	85	19	15	7.5

a. simplified as a square – has no influence on the calculated error.

The relation between DN and D_i is not linear at all but depends on various parameters:

1 the nominal diameter DN

2 the type of tube (steel tube, water pipe, concrete pipe, ...)

3 pressure stage

Hence this influence can not be considered sufficiently in the diagrams.

Just copy from the scans?

It is not desirable to use the old (scanned) diagrams as templates in all cases. Reasons are:

- The scans are imprecise, distorted and of low resolution (200 dpi).
- Most diagrams seem to be daughters or even grand children of original drawings. This is most evident with the diagrams using the US units.
- Lines are quite heavy which may impose a reading error up to 10% at tight diagram areas.
- In the diagrams the nominal diameters are displayed on an exact logarithmic scale. At least for small ratios DN/D_i this is not fully correct. Hence my impression is that accuracy of the diagrams was not a primary goal then.

Consequence

The newly drawn diagrams use D_i = DN. The cross section areas hence is $DN^2\pi/4$. This proceeding is supported by E+H Flowtec.

Note: *In the Flow handbook the text makes a remark concerning this.*

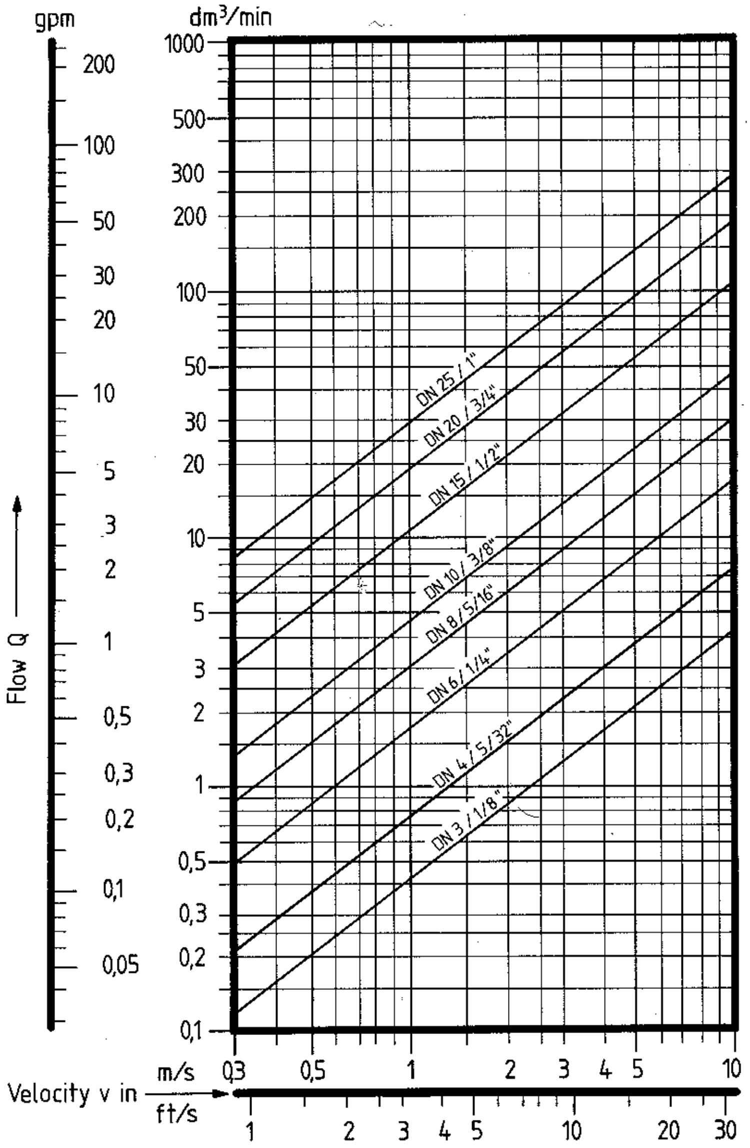
Drawing time

The time noted at the diagrams account only for the pure drawing. It does not include research and fine tuning of the appearance after comments by E+H Flowtec.

Diagrams in book appendix

Flow rate at small nominal diameters

Model



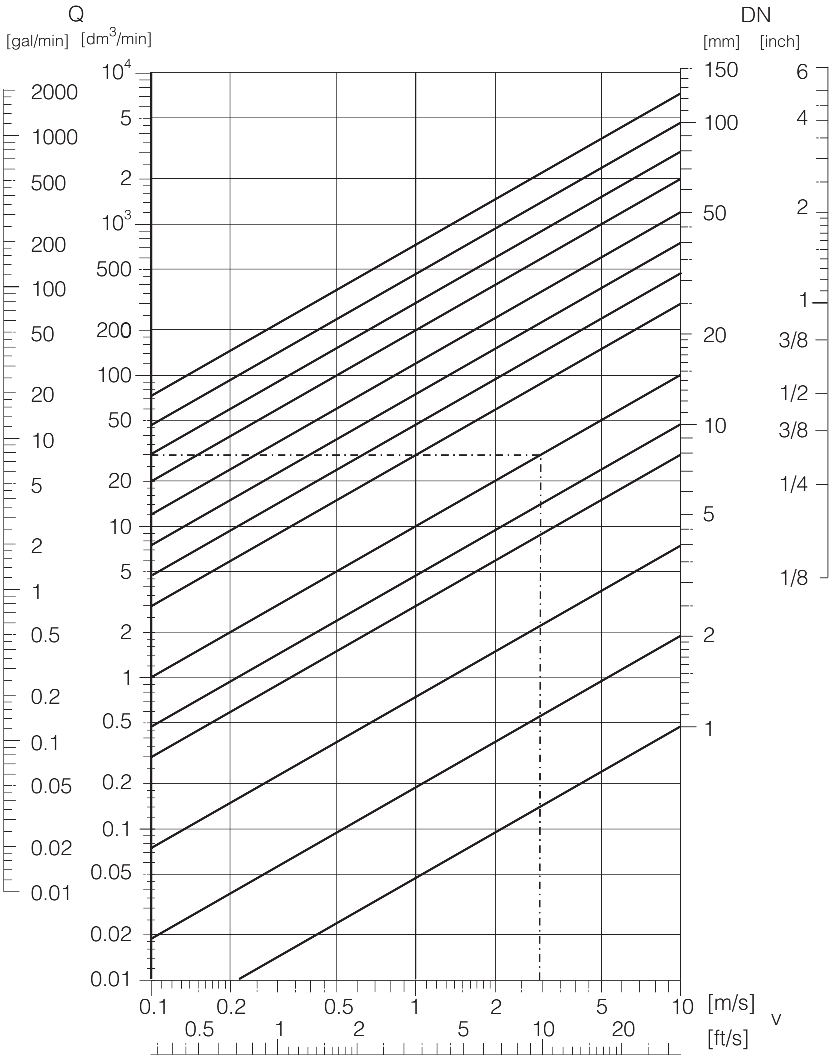
Example: *At flow rate 30 dm³/min and diameter 15 ➡ velocity is 2.75 m/s*

Remarks

Users want line diagrams (array of curves or lines), although alignment charts are more clear.

New diagram

File appendix-qv-1.eps



Drawing time 5 h

Example

Q= 30 dm^3/min, DN 15 ➔ v = 2.8 m/s (exactly: 2.83)

Equation

$$Q[\mathrm{dm^3/min}] = v[\mathrm{m/s}]\,60[\mathrm{s/min}]\,10[\mathrm{dm/m}]\frac{\pi}{4}d^2[\mathrm{mm^2}]\,10^{-4}[\mathrm{dm^2/mm^2}]$$

Diagram data

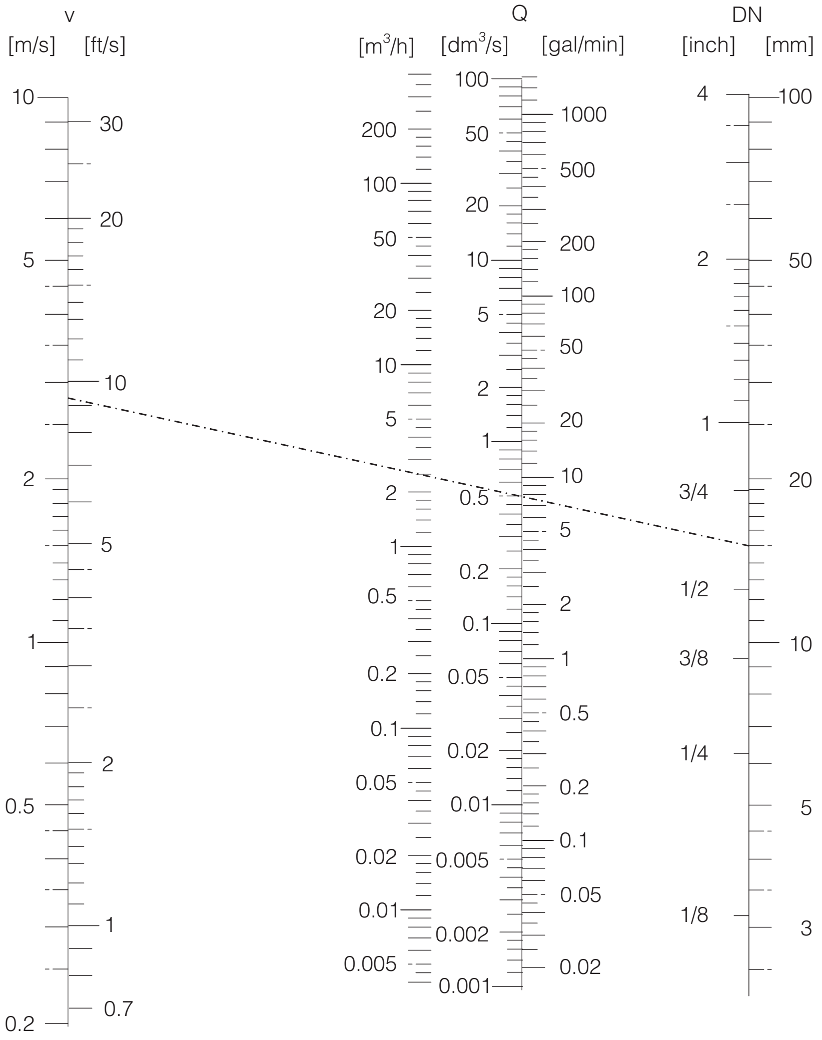
$e_Q = 20$; $e_v = 35$; $e_{DN} = 40$; tg$\alpha = 20/35$

Constants

1 USgal = 3.785 dm^3; 1 ft = 0.305 m

Alternative diagram

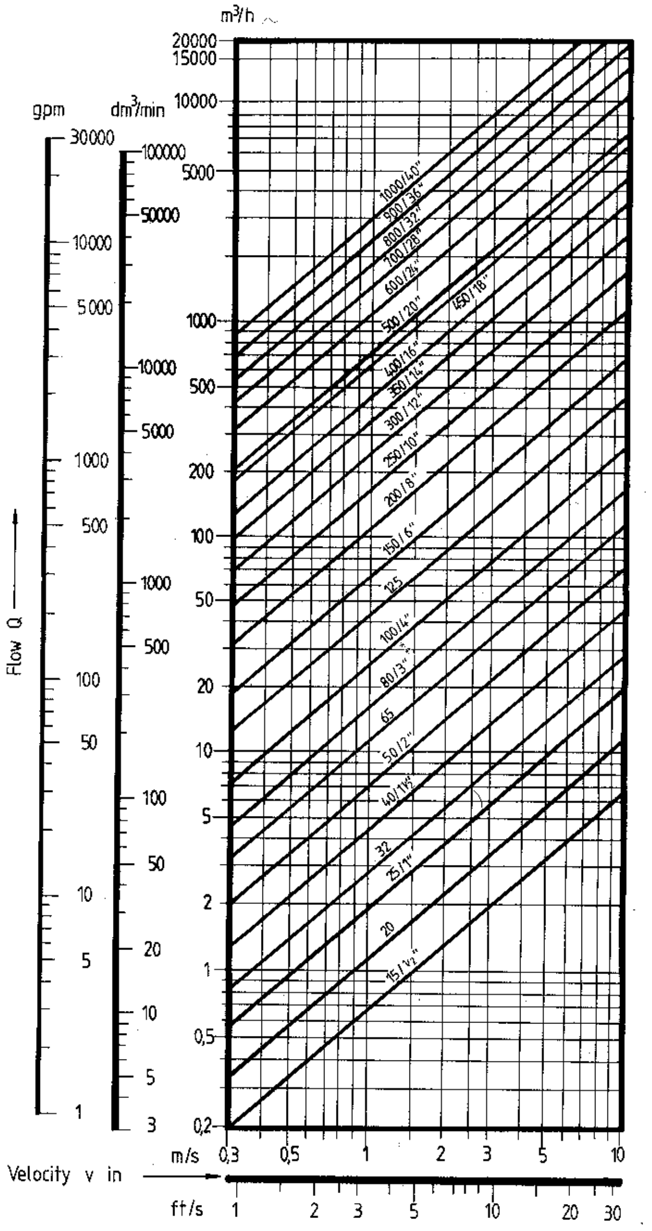
File appendix-qv-1a.eps



Drawing time 5 h

Flow rate at large nominal diameters

Model



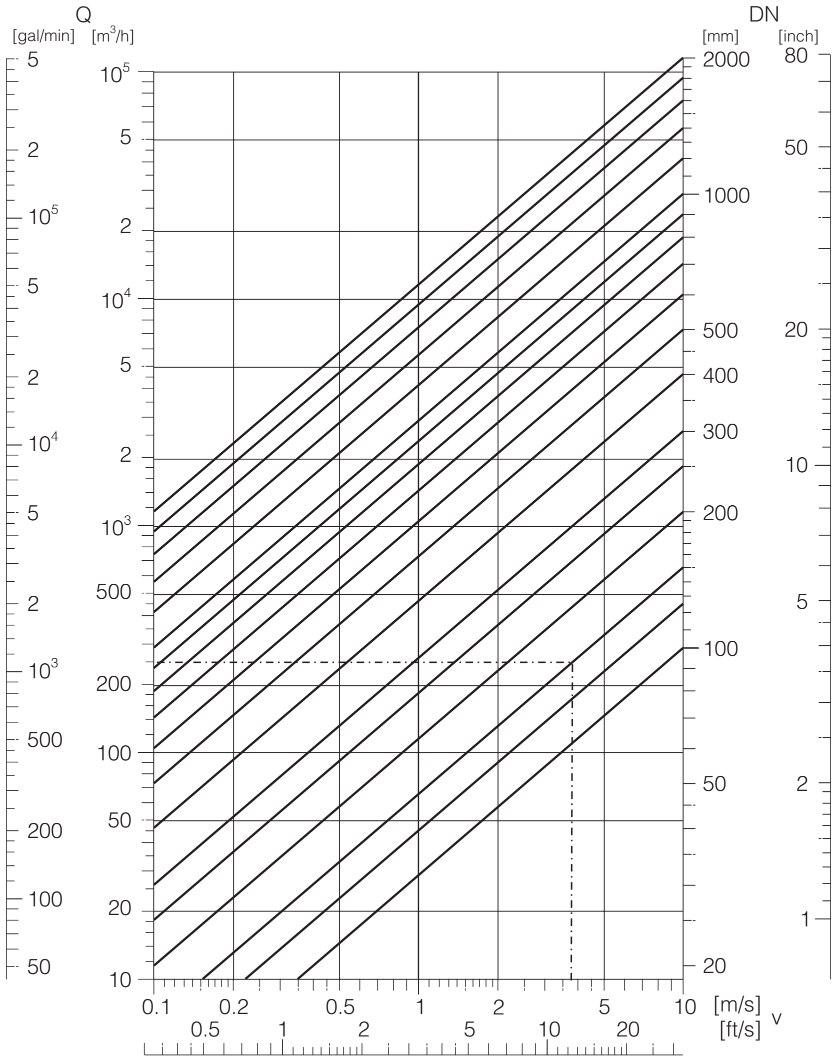
Example: *Flow rate 200 m³/h and diameter 150 gives velocity 3 m/s.*

Remarks

Users want line diagrams (array of curves or lines), although alignment charts are more clear.

New diagram

File appendix-qv-2.eps



Drawing time 5 h

Example

Q= 200 m^3/h, DN 150 ➔ v = 3.1 m/s (exactly: 3.144)

Equation

$$Q[\mathrm{m/h}] \;=\; v[\mathrm{m/s}]3600[\mathrm{s/h}]\frac{\pi}{4}d^2[\mathrm{mm^2}]10^{-6}[\mathrm{dm^2/mm^2}]$$

Diagram data

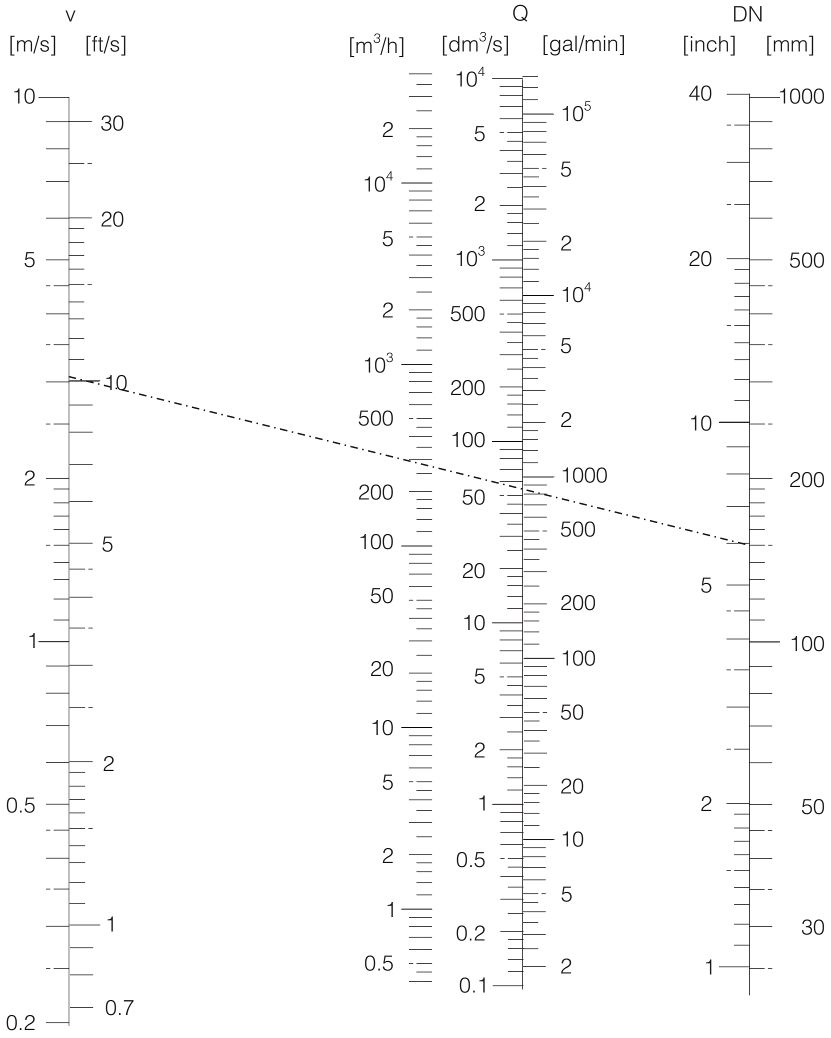
$e_Q = 30$; $e_v = 35$; $e_{DN} = 60$; $\mathrm{tg}\alpha = 30/35$

Constants

1 USgal = 3.785 dm^3; 1 ft = 0.305 m; 1 [gal/min] ➔ 0.2271 [m^3/h]

Alternative diagram

File appendix-qv-2a.eps



Drawing time 5 h

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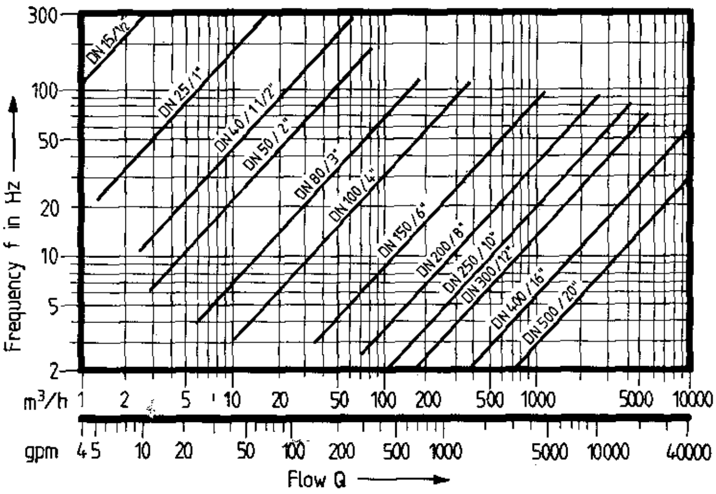
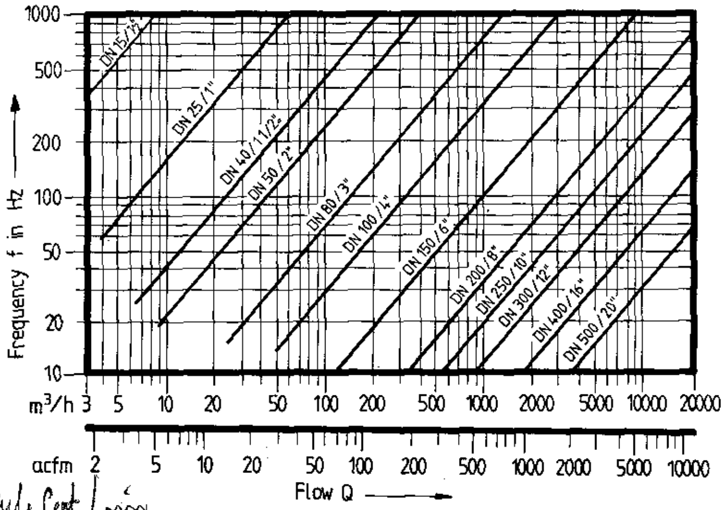
Vortex frequency in liquids and gases

Model



Tak

Ratio flow - vortex frequency gases



cub feet / min

Example: *The vortex frequency of a SWINGWIRL DN 100 at flow rate 200 m^3/h is 60 Hz.* ~~*(Liquids and gases have same frequencies)*~~

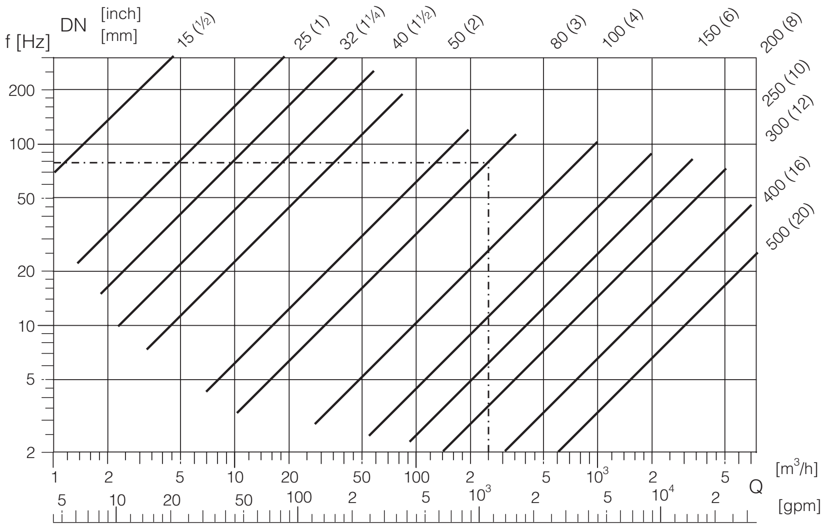
Remarks

Two diagrams are necessary because the length of the lines indicate the working area of the measuring devices – which are not identical for liquids and gases.

acfm: actual cubic feet/minute (air pressure considered).

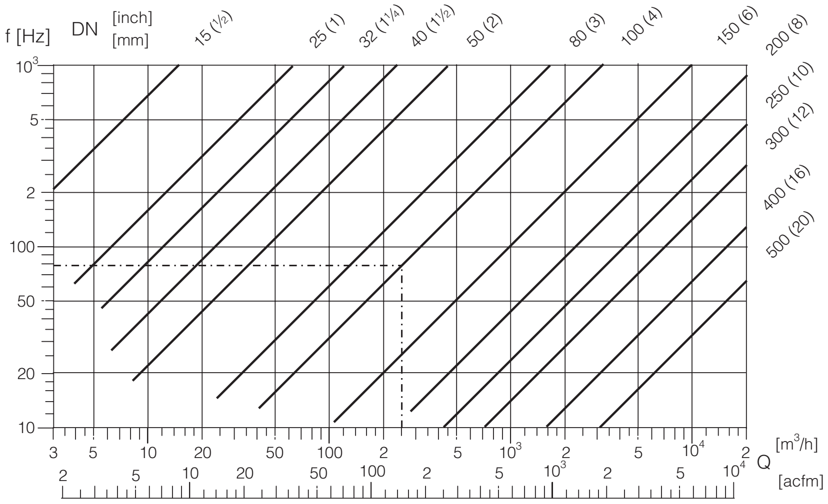
New diagrams

File appendix-vx-freq-liquid.eps



Drawing time 2.0 h

File appendix-vx-freq-gas.eps



Drawing time 2.0h

Example

The vortex frequency of a Swingwirl DN 100 at a flow rate of 200 m^3/h is 63 Hz.

Equation

$$Q = d^2 \frac{\pi}{4} v \rightarrow d = \sqrt{\frac{Q4}{v\pi}}$$

$$f[\mathrm{Hz}] = \frac{Stv}{d}$$

with St = Strouhal-number (value unknown)

➔ copying requested, although the diagrams could be comined and an alignment chart would be more clear.

Diagram data

$e_f = 24$; $e_Q = 24$; $e_D = 49$; $\mathrm{tg}\alpha = 1$

Constants

1 ft = 0.305 m; 1 acfm = 0.305^3 [m^3/min] = 1.699 [m^3/h]
1 gpm [gal/min] = 0.2271 [m^3/h]

Excursus about the Strouhal number

This section presents the result of the e-mail correspondence with [Sturmayr].

The Strouhal number depends on the geometry (form) as well as the Reynolds and Mach number. The diagrams are obviously both logarithmic and in physical entities linear, that is,

$$\ln f = a \ln v + b \quad \text{or} \quad f = b v^a \quad \text{linear for} \quad a = 1 \quad ;$$

whereas $b = \frac{\mathrm{St}}{d}$

The diagrams assume that the Strouhal number depends only on the geometry and the characteristic length and hence are constnat for a given nominal diameter. A possible small dependence on velocity, viscosity and Mach number is not considered in the diagrams.

The Strouhal number does not depend on the medium. Gases and liquids differentiate only in their compressability (‘high’ for gases, ‘low’ for liquids). Above the critical pressure of the medium in question only a liquid phase exists which exposes the typical high density of liquids and the typical high compresseability of gases.

As long as the Mach number is smaller than 0.3 flowing gases are approximately incompressible. This criterion is relevant in flows within plants, where they normally are held true.

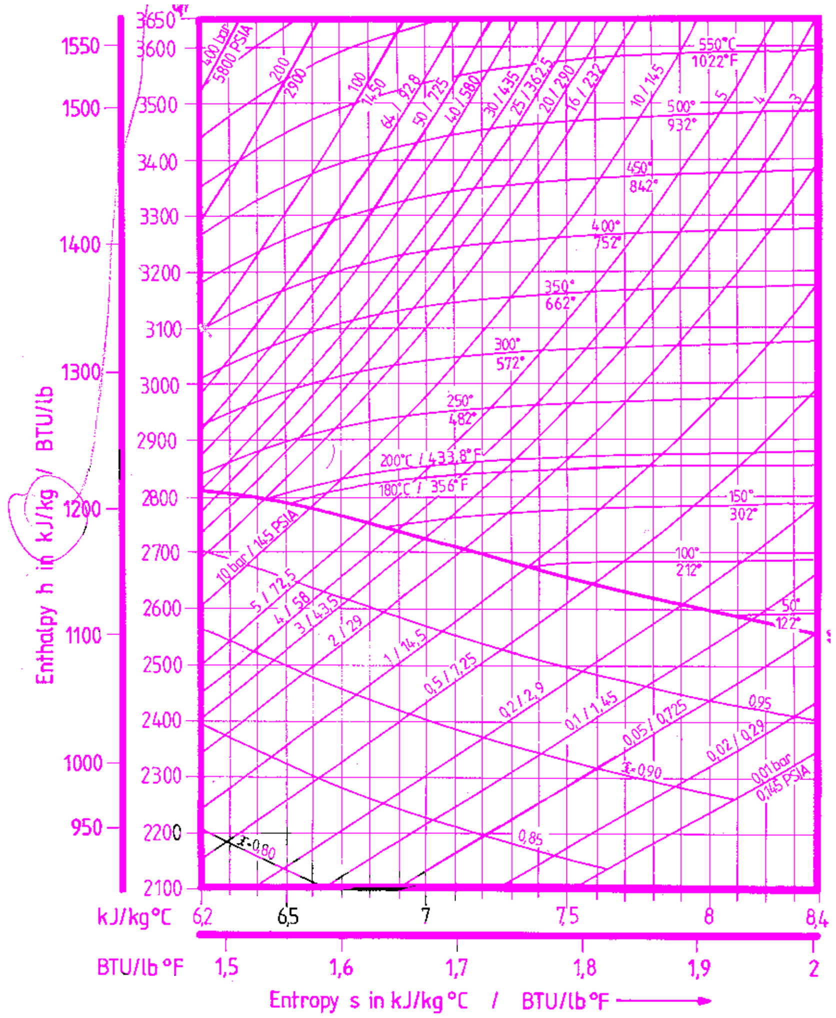
The Strouhal numbers for the various nominal diameters have certainly been found by experiments: hence either call for the original data or copy from the existing diagrams.

The ends of the characteristic curves could indicate the functional area of the respective SWINGWHIRL. The functional area may well be different for gases and liquids (no clean unwinding of the vortex beyond the end of the characteristic lines.

To press 100 m3/h through a 10mm pipe is excessive (and possibly outside the functional area, but not necessarily impossible. Self induced oscillations with 30 kHz are definetely possible).

Mollier diagram

Model



Example: *Steam at 1 bar absolute pressure and 150°C is overheated; it has an enthalpy of 2780 kJ/kg and an entropy of 7.62 kJ/kg grd.*

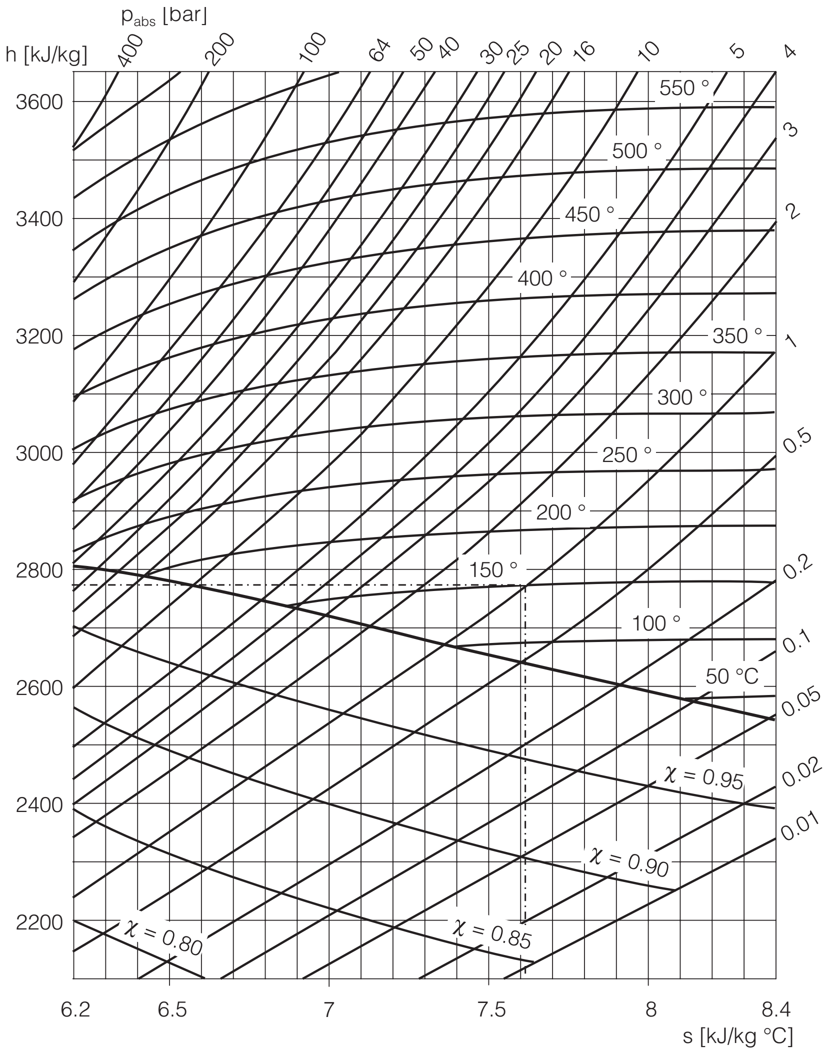
Remarks

To reduce compexity draw distinct diagrams for SI and US units.

psia: psi absolute

New diagrams

File appendix-mollier-si.eps



Drawing time 7.0 h

Example

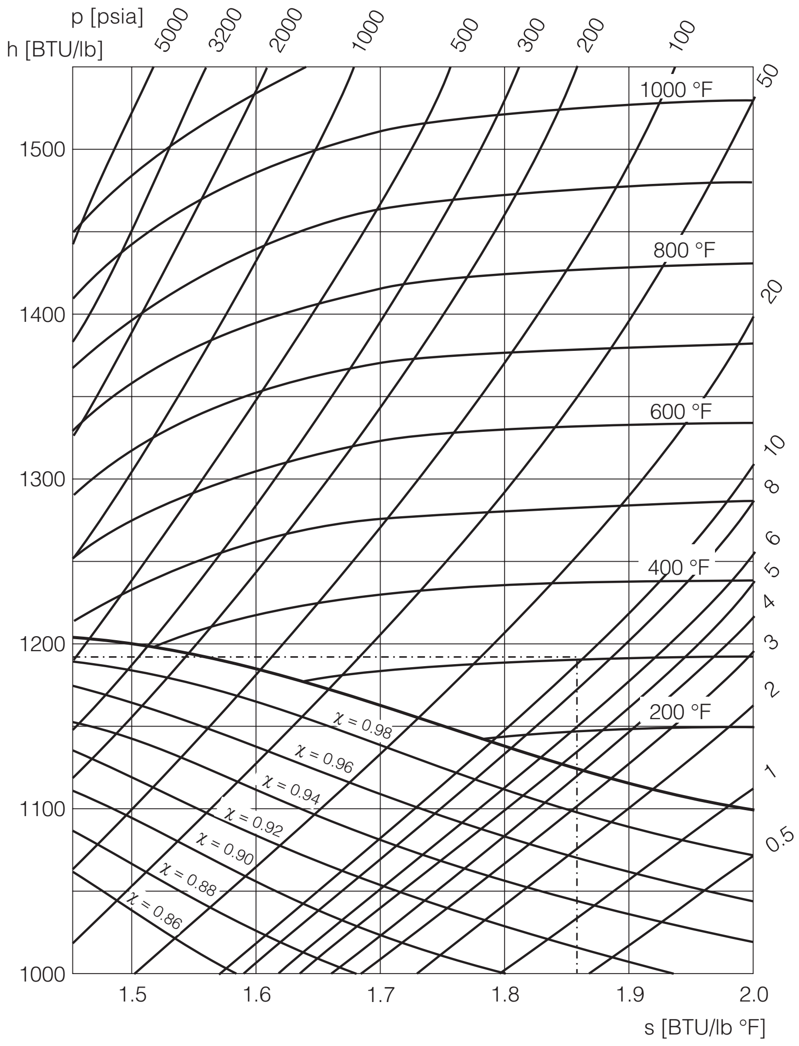
Steam with 1 bar at 150 ˚C is overheated
➔ Enthalpy 2780 [kJ/kg], Entropy 7.62 [kJ/kg ˚C]

Diagram data

e_h = 77/1000; e_s= 42; curves copied from [Çengel], althour the diagram therein displays a very large range.

Note: *In place of [kJ/kg ˚C] also [kJ/kg ˚K] is in use.*

File appendix-mollier-us.eps



Drawing time 3.0 h + 2h corrections according to new sources.

Example

Steam at 10 PSIA at 300 ˚F is overheated
➔ enthalpy 1190 [BTU/lb], entropy 1.86 [BTU/lb ˚F]]

Diagram data

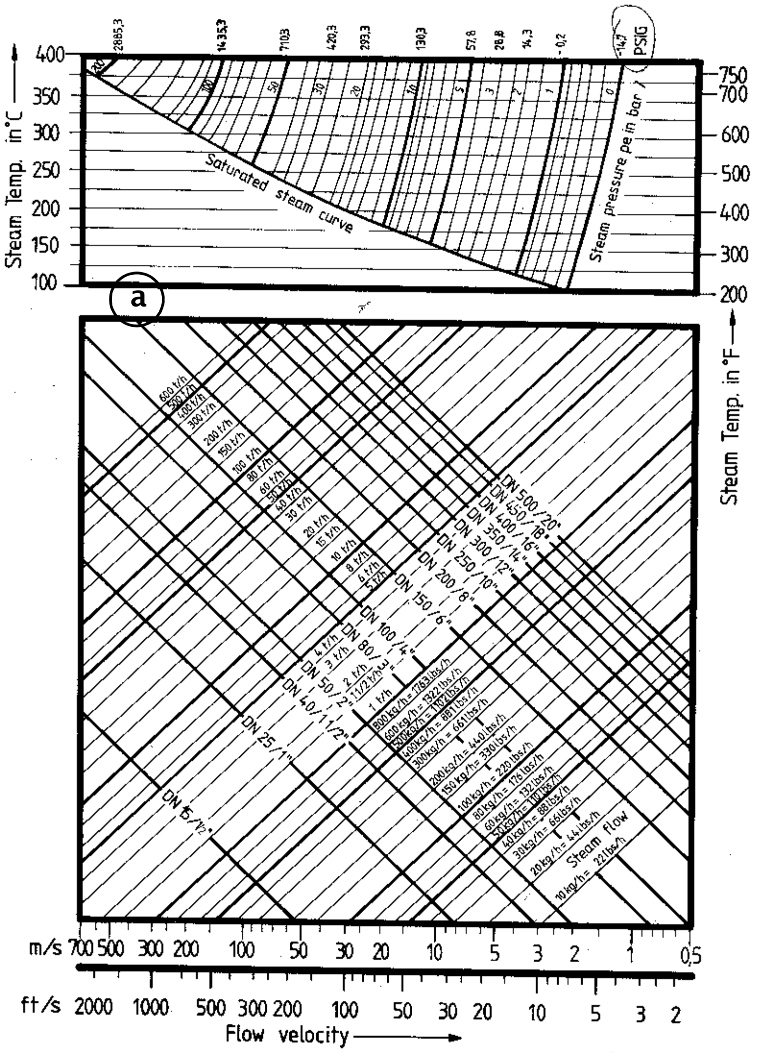
e_h = 109/500; e_s= 164; kurven aus [Çengel], anhang 2.

www.genphysics.com, leaflet for GPSteam Version 4.0 (Steam Property calculator) is too small for copy.

Note: *In place of [BTU/lb ˚F] also [BTU/lb ˚R] is in use. R is abbreviation for Rankine, not for Reaumur!*

Flow velocities in steam applications

Model



Remarks

Leave diagram in this form, however reduce number of lines,e.g. leave out DN 350 and 450. US units in same diagram.

psig: psi excell pressure (air pressue considered), gauge display

[Sturmayr] (a) is the density ρ, more exactly the specific volume 1/ρ. Carefully distinguish between mass flow rate - ($\dot{m}$) volume flow rate (Q):

$$\dot{m} = \rho Q \qquad \text{oder} \qquad Q = \dot{m}\frac{1}{\rho}$$

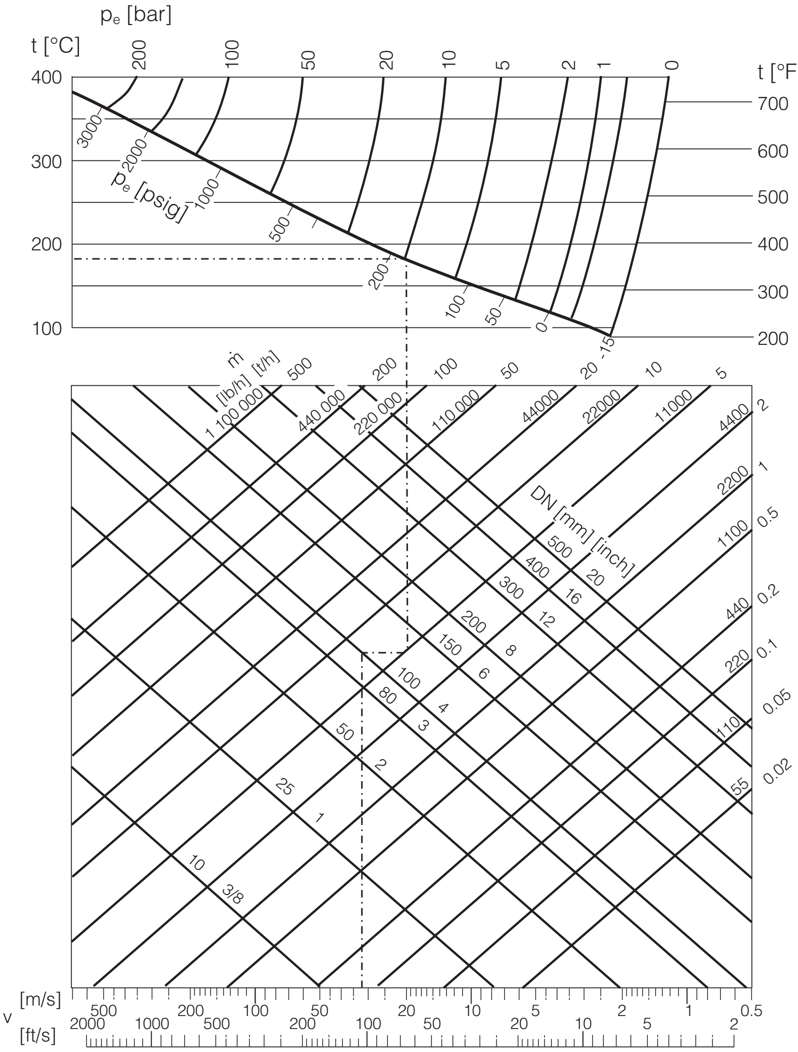
The ordinate in the lower diagram is the volume flow rate (logarithmic scale). The DN lines (lower scale and missing, but not needed left scale) display the linear dependance of the volume flow rate from the volocity (at a constant pipe cross section).

The lines for the mass flow rate (missing scale above and to the left – both are not required) display the liniear dependance of the volume flow rate from the specific volume (at a constant masse flow rate, see equation).

For calculating new data for the steam diagrams a saturation equation and probably an equation of state for the upper diagram is required.

New diagram

File appendix-steam-1.eps



Drawing time 7.0 h

Example

Steam pressure 10 [bar] (gauge), temperature T=183 [˚C] (saturated steam) yields a throughput of 5 [t/h] and with DN 100 a flow velocity of 50 [m/s].

Diagram data

Steam data according to VDI Dampftafel; $e_t = 11$; e_p is not logarithmic, $e_m = 26$: $e_{DN} \approx 36.8$, $\alpha = -40^\circ$(copied, adapted), $e_m \approx 27.5$, $\alpha = 40^\circ$(copied, adapted), $e_v = 28.5$ (copied, adapted)

$\dot{m}$ is the mass flow rate[kg/m^3]. v [m^3/kg] is the hidden abcissa between the two diagram parts.

Constants

1 ft = 0.305 m; 1 psi = 0.069 [bar]; 1 lb = 0.454 [kg]

psig is excessive pressure (gauge)

Steam data

v ... specific volume, t ... steam temperature, p_e ... steam pressure (gauge)

Saturated steam

p_e [bar]	0	1	2	5	10	20	50	100	200
t [°C]	99.1	119.6	133	158	183	214	263	309.5	364
v [m^3/kg]	1.725	0.9	0.62	0.32	0.18	0.097	0.043	0.019	0.007

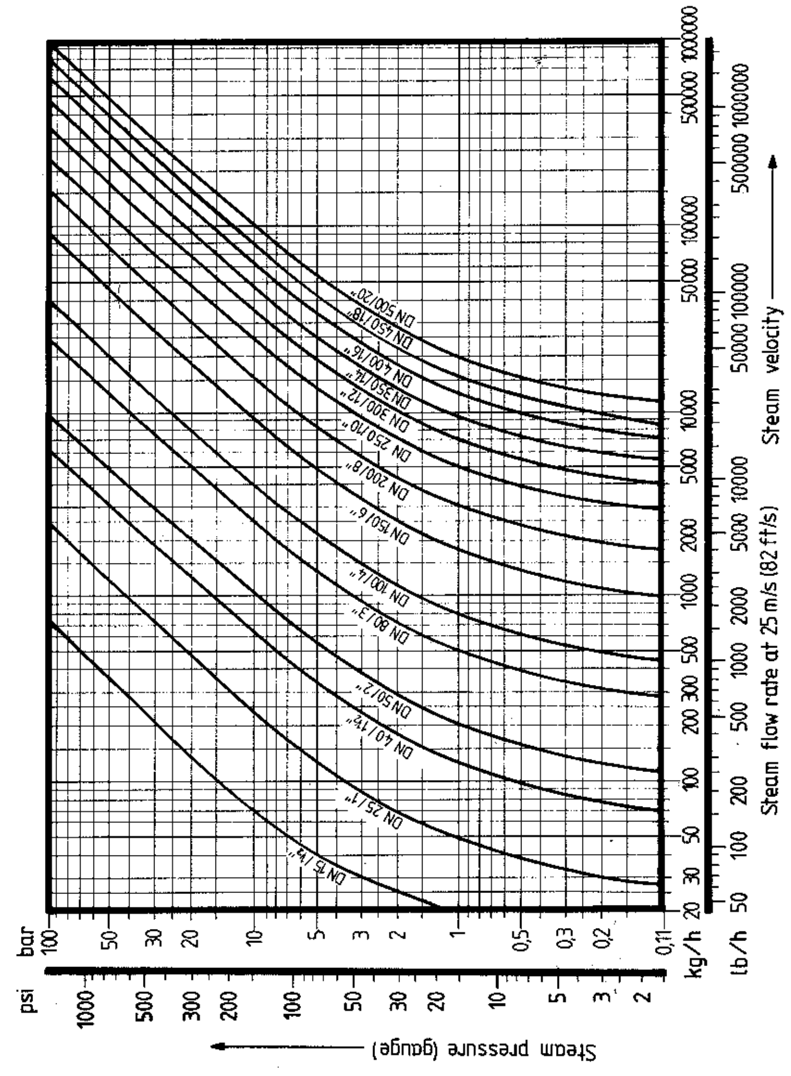
v ... specific volume

Overheated steam

p_e [bar]	5	10	20	50	100	200
t = 250 °C	0.343	0.215	0.108			
t = 400 °C	0.448	0.284	0.147	0.059	0.027	0.01

Saturated-steam flow rates

Model



Example: *2000 kg/h vapour flow rate at 4 bar excess pressure*
➥ DN 100 is ideal.

Remarks

Leave diagram in this form, but reduce number of lines..

[Sturmayr] Abscissa is the mass flow rate $\dot{m} = \rho v A$

(v velocity, A pipe cross section), Ordinate is pressure. For saturated steam density depends only on pressure.

$$\rho = \rho(p) \qquad \text{oder umgekehrt} \qquad p = p(\rho)$$

For a particular curve, eb. DN 100 both mass flow rate and area A are constant. Reading the diagram conventionally displays:

$$p(\rho) \qquad \text{wobei} \qquad \rho = \frac{\dot{m}}{vA}$$

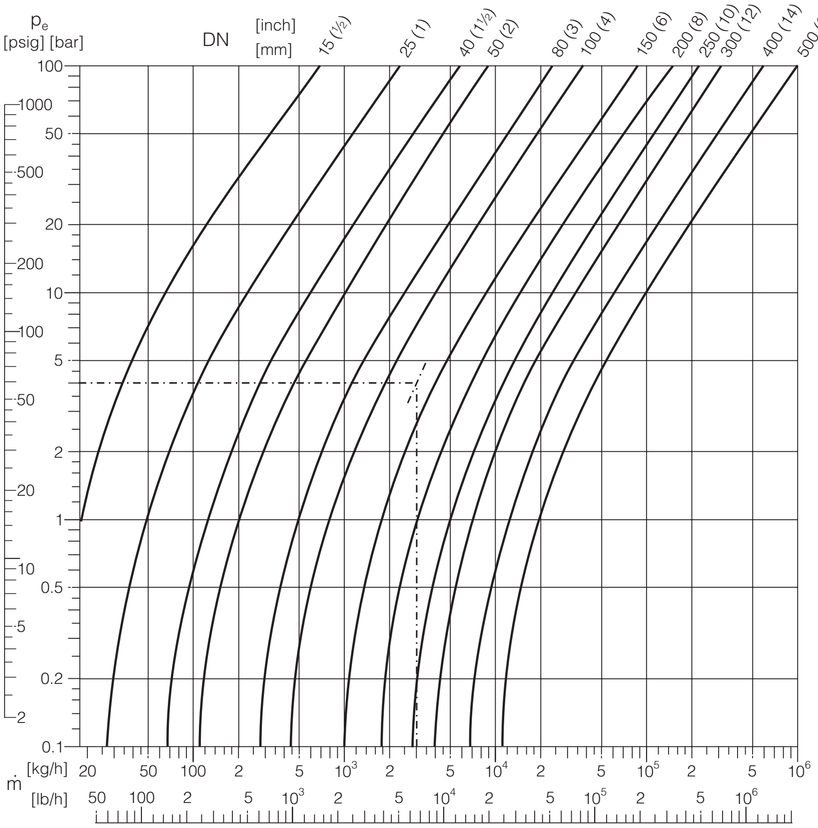
Since v and a re constant ρ becomes a linear function of the mass flow rate. If the ordinate would be the density ρ then the DN lines would be straight lines. The current bent DN lines implicitly contain the dependancy pressure/density at saturation.

The diagram is valied for v = 25 m/s which is economic for steam in pipes.

New diagram

These look completely different - but are just turned 90˚.

File appendix-steam-2.eps



Drawing time 4 h

Example

The nomogram above shows saturated-stem flow rates for a flow volocity = 25 m/s.

Steam flow rate of 3000 [kg/h] at 4 [bar] (gauge) ➔ DN 100 to 150 is ideal for these process conditions.

Diagram data

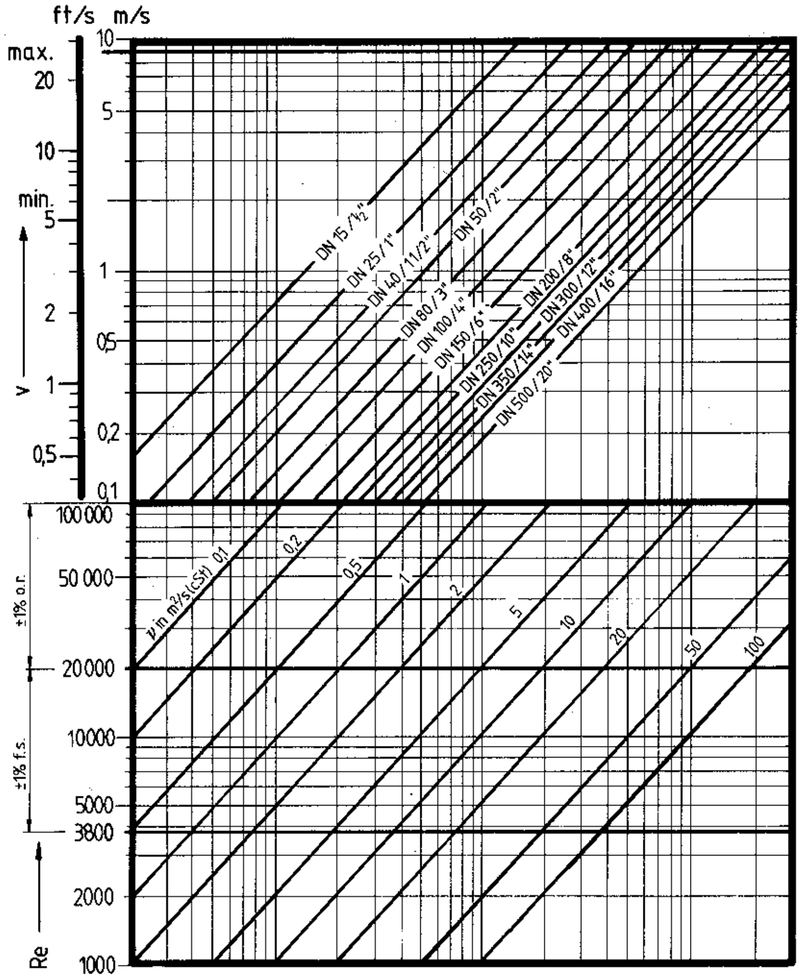
$e_p = 30$; $e_{DN} \approx 103$; $e_m = 20$; curves copied

Constants

1 psi = 0.069 [bar]; 1 lb = 0.454 [kg]

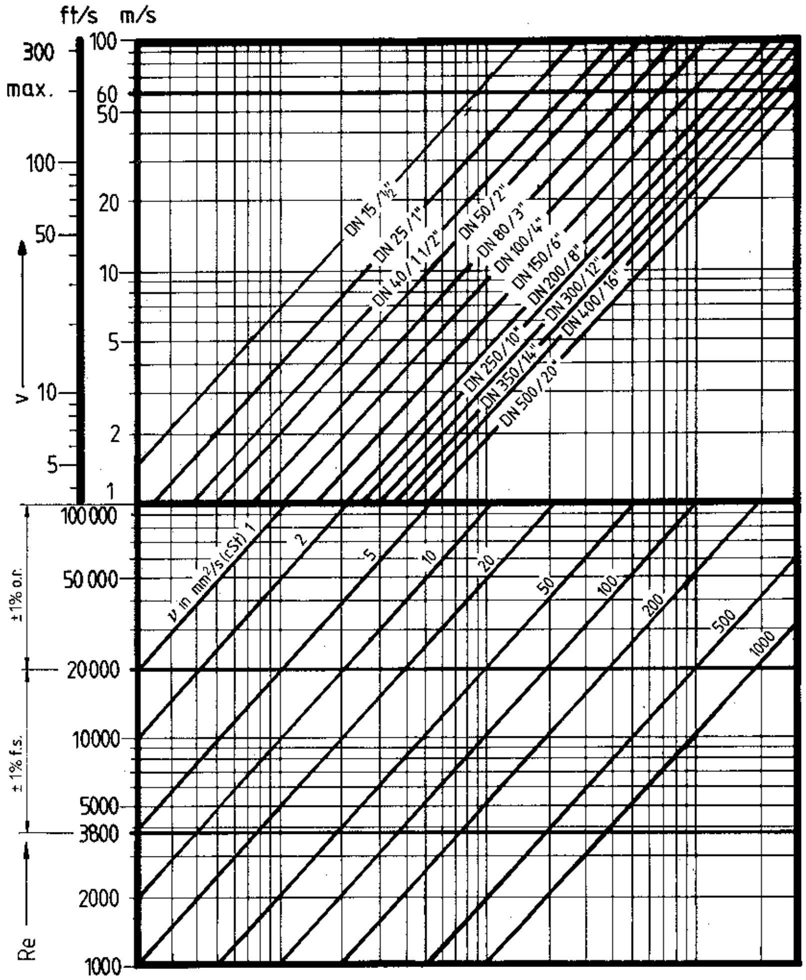
Reynolds number - flow velocity - viscosity

Model for liquids



Example: *At v = 0.4 m/s, a nominal diameter of 150 and a viscosity of 10 cst (mm^2/s) the Reynolds No. is 6200. This lies in the measuring range with an accuracy of ± 1% o.f.s. (of full scale).*
For Re No. ≥ 20000 therefore in range ±1% o.r. (of rate)
Re 20000, 10 cSt, DN 150 ➥ 1.3 m/s

Model for gases



Example: *Velocity 50 m/s, DN 80, viscosity 50 mm^2/s ➡ Re = 80000 i.e. greater than Re 20000, therefore in range ±1% o.r.*

Remarks

These two diagrams can be combined into one alignment chart.

The ranges for the accuracy meet at Re = $2 \cdot 10^4$ hence only a one-pointed arrow is nescessary.

Data must be calculated anew, the old diagrams have an error of $\pi/4$.

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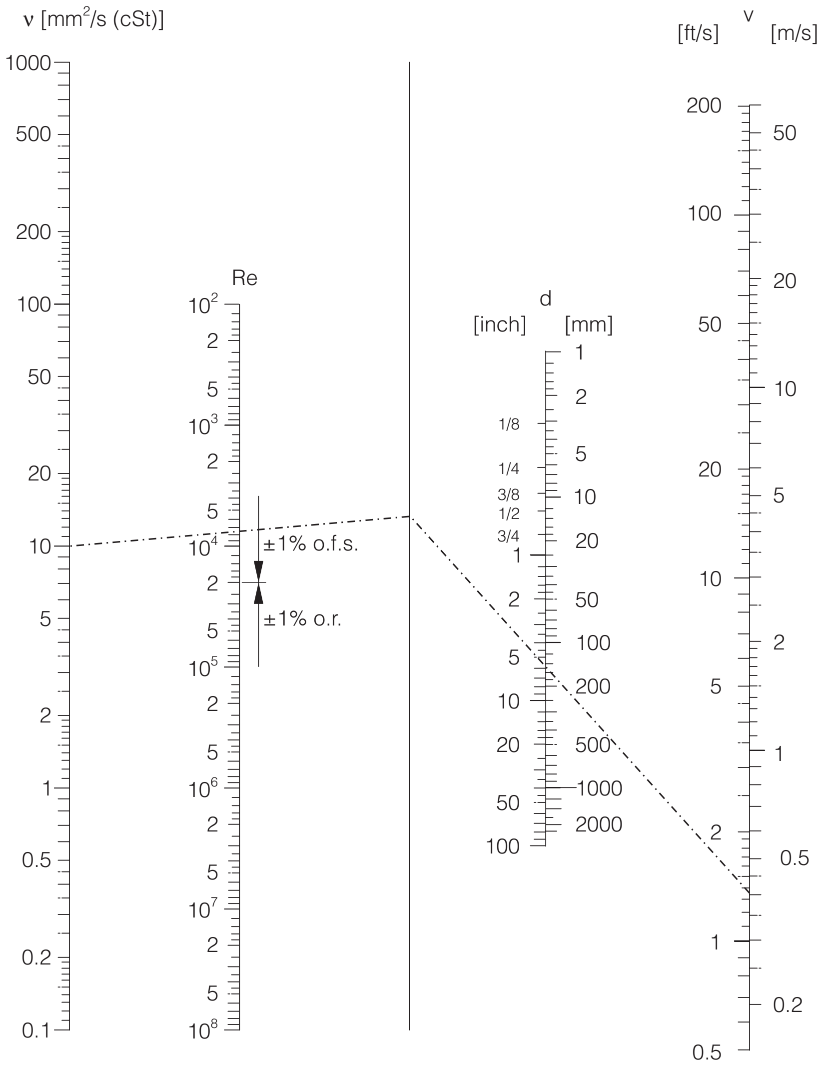
New diagram

File appendix-vx-re-liq&gas.eps



Drawing time Ca 7.0 h including development

Examples

v= 0.4 [m/s], ND= 150, ν= 10 [cSt= mm^2/s] ➔ Re = 7500 ≥ ± 1% of full scale.

v= 50 [m/s], ND= 80, ν= 50 [cSt= mm^2/s] ➔ Re= 100 000 ≥ ± 1% of reading.

Note: *Only the first example is drawn.*

Equation

$Re = \frac{vd}{\nu}$; ν [mm^2/s = cSt]

Diagram data

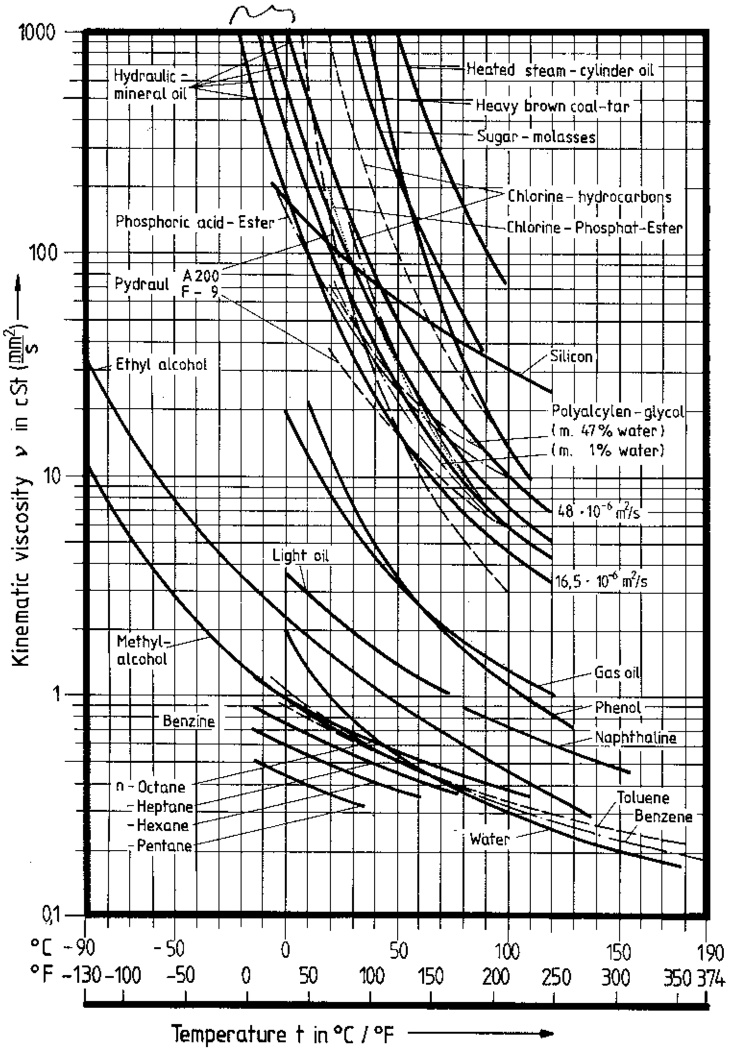
$e_\nu = 32$; $e_{Re} = 16$; $e_{DN} = 20$; $e_V = 48$; $a_{\nu\text{-}V} = 22.5$; $a_{V\text{-}DN} = 27$; $a_{\nu\text{-}V} = 90$.
Re-range has been extended in both directions.

Constants

1 ft = 0.305 m

Kinematic viscolity - temperature (liquids)

Model



Example: *The cinematic viscosity of silicon at 80°C is*

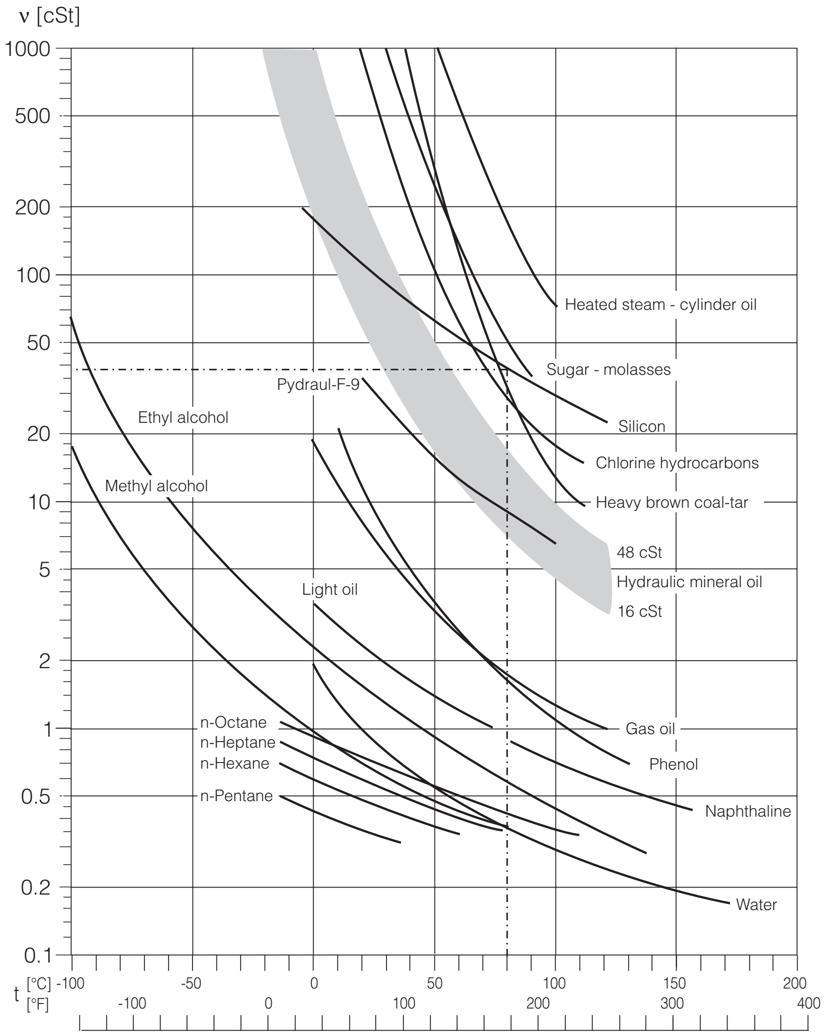
$$4 \cdot 10^{-5} \frac{m^2}{s} = 40\ cSt$$

Remarks

Combine curves in the shaded area, if only the first and last curve in this area have values. Some curved may be dismissed, if area to crowded.

New diagram

Files appendix-temp-viscos-liquid_de.eps,
appendix-temp-viscos-liquid_en.eps



Drawing time

6 h + 1h for the english texts

Example

The kinematic viscolity of silicon at 80 [°C] is 40 [cSt] = 40 [mm^2/s].

Diagram data

e_ν = 30; e_t = 32/100 °C; curves copied and some dismissed.

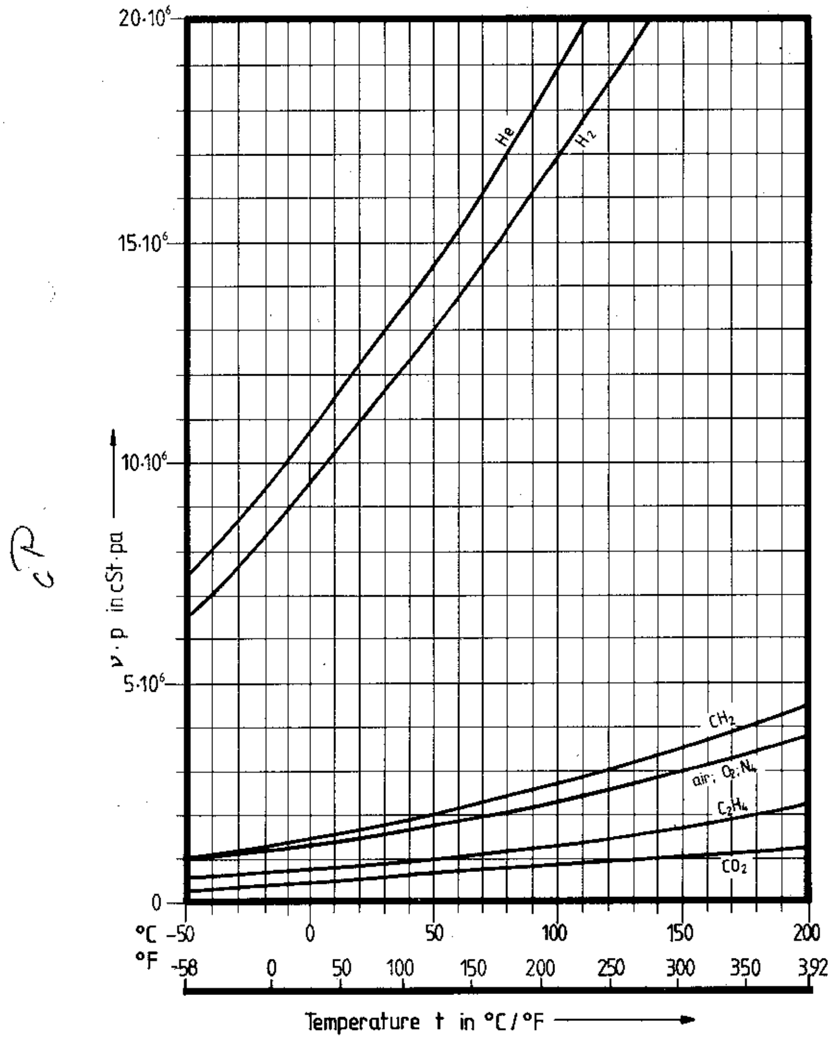
Constants

°F = 1.8 °C + 32;

°F	-150	-100	0	100	200	300	350
°C	-101	-73	-18	37.8	93.3	149	177

Kinematic viscosity - temperature (gases)

Model



Example: *He 80°C* $\Rightarrow \upsilon \cdot p = 17 \frac{m^2}{s}$ *Pa*

To calculate υ *at a certain pressure, multiply the value by p in Pa* (*1 bar =* 10^5 *Pa =* 10^5 *N/m*^{2})

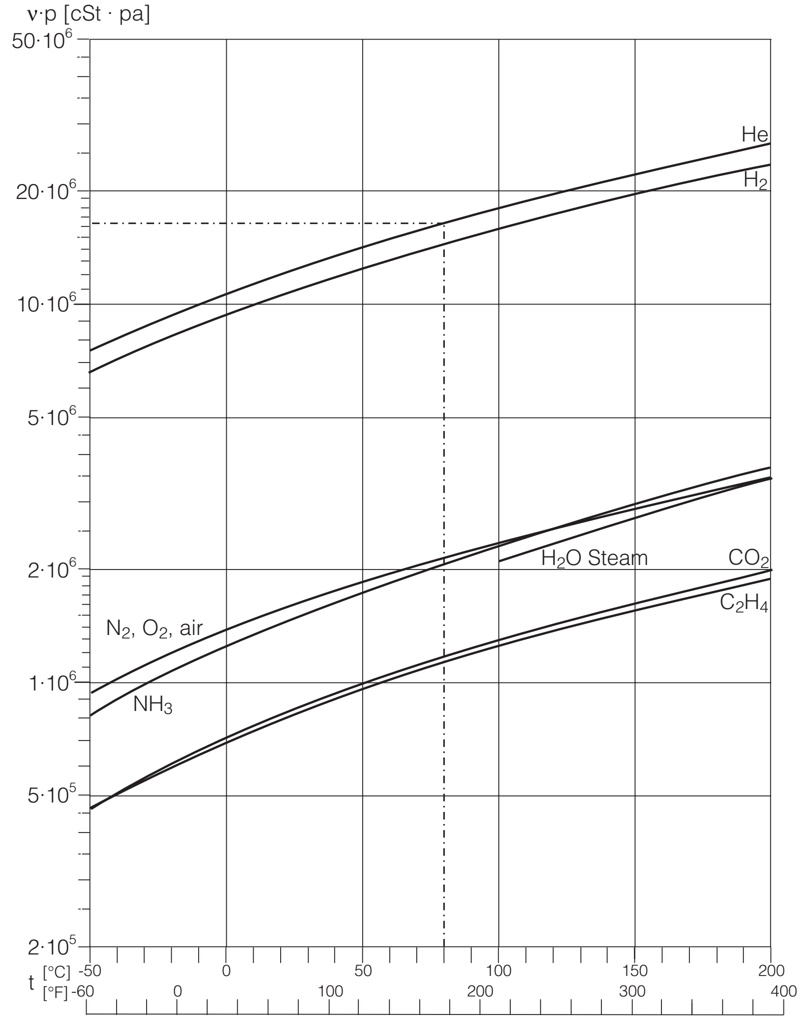
Remarks

The diagram seems to be valid at $p_0 = 1$ [bar]. Ordinate: cSt (centiStokes) × pa (Pascal), to be able to convert to other pressures.

Gases CH_2 and $(CH_2)_2$ do not exist; C_2H_4 is ethylene. Also N_4 does not exist, should probably be N_2. The values do not correspond well with new sources.

New diagram

File appendix-temp-viscos-gas-de.eps
appendix-temp-viscos-gas-en.eps



Drawing time

2.5 h + 5h verification and research of data

Example

Helium 80 °C ➔ ν * p = 16.3 [m^2/s * Pa]

Equation

ν_p [cSt]= p_0 [cSt/Pa] * p [Pa]

Constants

1 Pa (Pascal) = 10^{-5} [bar]; cSt * pa

Note: *O_2 and N_2 have nearly the same values as air, hence no separate curves.*

Diagram data

$e_v = 50$; $e_t = 18/50$ °C

Material data

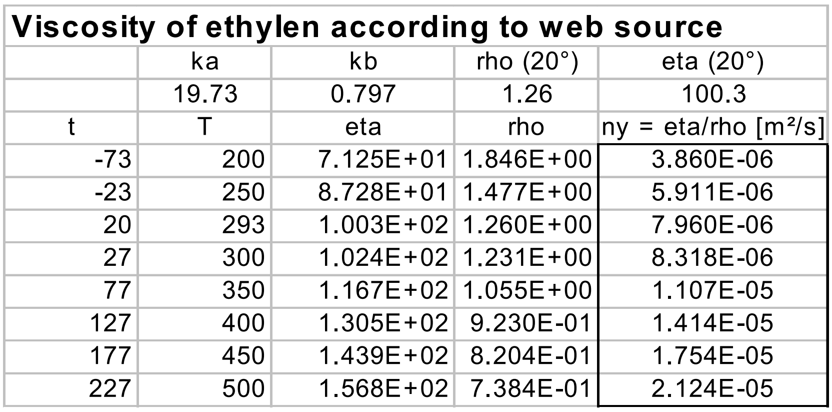
Dynamic viscosity according to [Çengel]; for ethylen according to [web1]:

At 20°C: η = 100.3 x 10^{-7} Pa s; ρ = 1.26
➔ ν = 0.796 x 10^{-5} [m^2/s].
Table values calculated according to :

$$\eta = \eta_{20}\left(\frac{T}{293}\right)^{\frac{A}{T}+B} \quad \rho = \rho_{20}\frac{T_{20}}{T} \quad \nu = \frac{\eta}{\rho} \quad (A=19.73;\ B=0.797)$$

°K	200	250	300	350	400	450	500	
°C	-73	-23	27	77	127	177	227	m^2/s
Air	0.76	1.14	1.57	2.06	2.60	3.18	3.80	$\times 10^{-5}$
Ammonia	0.66	1.03	1.48	2.03	2.68	3.42	4.25	$\times 10^{-5}$
Ethylen	0.86	0.59	0.83	1.11	1.41	1.75	2.12	$\times 10^{-5}$
Carbon dioxide	0.38	0.59	0.84	1.13	1.45	1.90	2.19	$\times 10^{-5}$
Helium	0.61	0.90	1.22	1.59	1.99	2.43	3.90	$\times 10^{-4}$
Hydrogen	0.55	0.80	1.09	1.42	1.78	2.17	2.59	$\times 10^{-4}$
Nitrogen, Oxygen	0.75	1.13	1.58	2.09	2.63	3.21	3.80	$\times 10^{-5}$
Steam	at saturation		36.1	4.33	2.38	3.10	3.92	$\times 10^{-5}$

Excel sheet for the ethylen calculation:

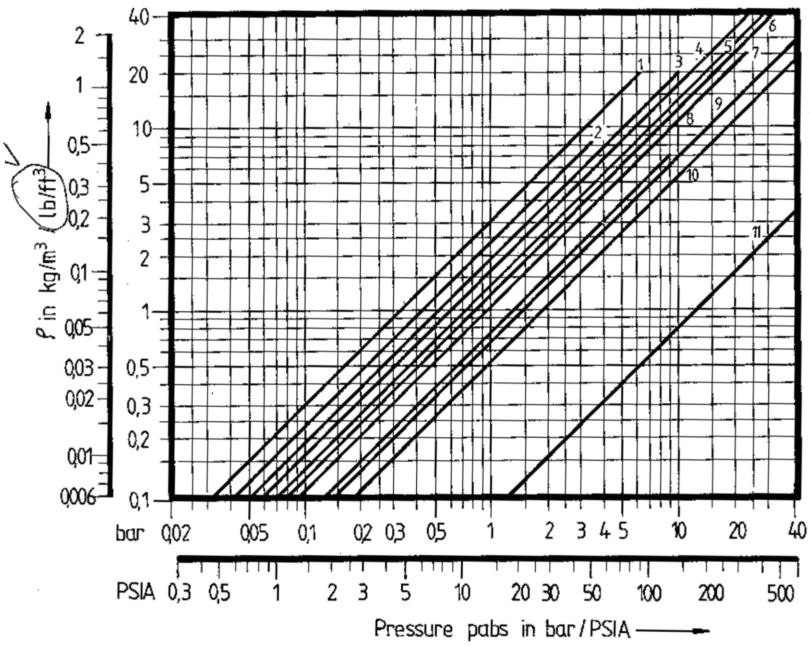


Viscosity of ethylen according to web source

	ka	kb	rho (20°)	eta (20°)
	19.73	0.797	1.26	100.3
t	T	eta	rho	ny = eta/rho [m²/s]
-73	200	7.125E+01	1.846E+00	3.860E-06
-23	250	8.728E+01	1.477E+00	5.911E-06
20	293	1.003E+02	1.260E+00	7.960E-06
27	300	1.024E+02	1.231E+00	8.318E-06
77	350	1.167E+02	1.055E+00	1.107E-05
127	400	1.305E+02	9.230E-01	1.414E-05
177	450	1.439E+02	8.204E-01	1.754E-05
227	500	1.568E+02	7.384E-01	2.124E-05

Density and pressure of various gases

Model



For fluctuating temperature around t 0°C: ρ is calculated as:

$$\rho_t = \rho_1 \frac{273^\circ C}{273^\circ C + t}$$

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

Example: *Density of acetylene (No. 7) at 12 bar absolute pressure is 13 kg/m³ at 0°C.*

At 50°C: $\rho_{50^\circ C} = 13 \frac{273}{273 + 50} = 11\ kg/m^3$

Remarks

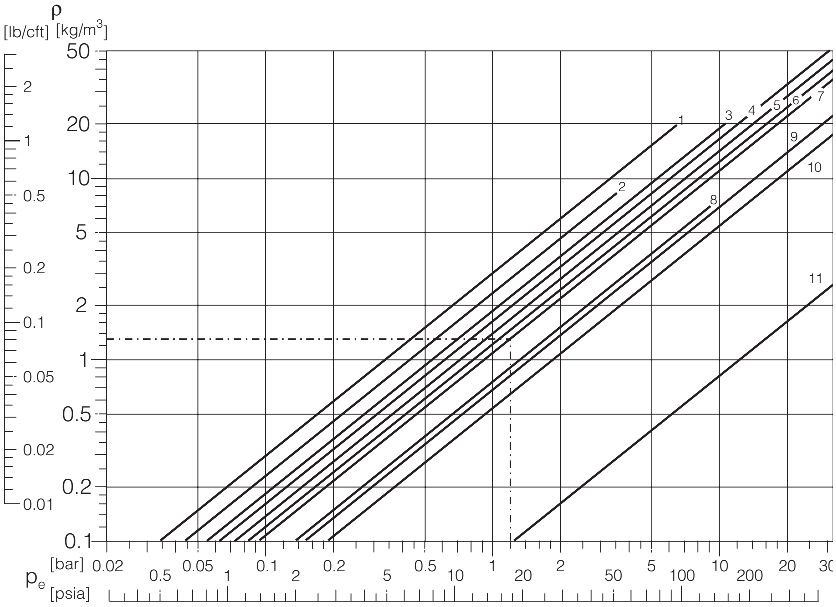
More data for ν could be calcuated by the program Pressure-Drop.

Although the diagram shall not be converted to an alignment chart I nevertheless deveoped one to show the difference.

In the line diagram the length of the lines indicate the valid range.

New diagram

File appendix-density-pressure.eps



Drawing time

2.5 h

Nr	deutsch	english	Nr	deutsch	english
1	Chlorgas	Chlorine	7	Acetylene	Acetylene
2	Butan	Butane	8	Ammoniak	Ammonia
3	Porpan	Propane	9	Methan	Methane
4	Kohlendioxyd	Carbon dioxide	10	Stadtgas	City gas
5	Luft	Air	11	Wasserstoff	Hydrogen
6	Stickstoff	Nitrogen			

Example

Density of acetylene (7) at 1.2 [bar] absolute pressure and 0 ˚C is 1.3 [kg/m^3]

At 50 [˚C] the value is 1.1 [kg/m^3] according to the equation.

Equation

For temperatures around 0 ˚C : $\rho_t = \rho_0 \frac{273\ [°C\ ]}{273 + t\ [°C]}$

Diagram data

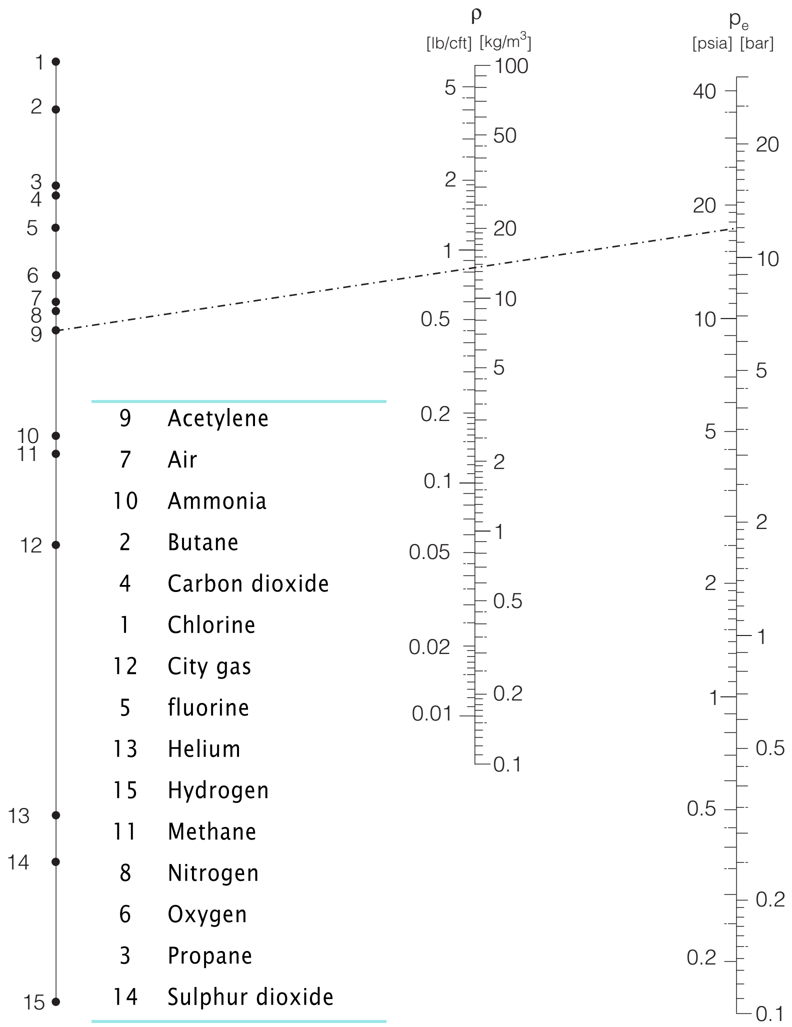
$e_\rho = 30$; $e_p = 24$; tg $\alpha = 24/30$

Constants

1 [lb/cft] = 16.02 [kg/m^3]; 1 [psia] = 0.069 [bar]

Alternative diagram

File appendix-density-pressure1.eps



9	Acetylene
7	Air
10	Ammonia
2	Butane
4	Carbon dioxide
1	Chlorine
12	City gas
5	fluorine
13	Helium
15	Hydrogen
11	Methane
8	Nitrogen
6	Oxygen
3	Propane
14	Sulphur dioxide

Drawing time

3.0 h (incl. development, find the γ-values)

Example

Density of acetylene (7) at 12 [bar] absolute pressure and 0 °C is 13 [kg/m^3]

At 50 [°C] the value is 11.4 [kg/m^3] according to the equation.

Diagram data

e_γ = 80 (for placement of dots); e_ρ = 30.8; e_p = 50; $a_{k\text{-}p}$ = 90; $a_{k\text{-}\rho}$ = 55.4. Data according to [Vogel].

Constants

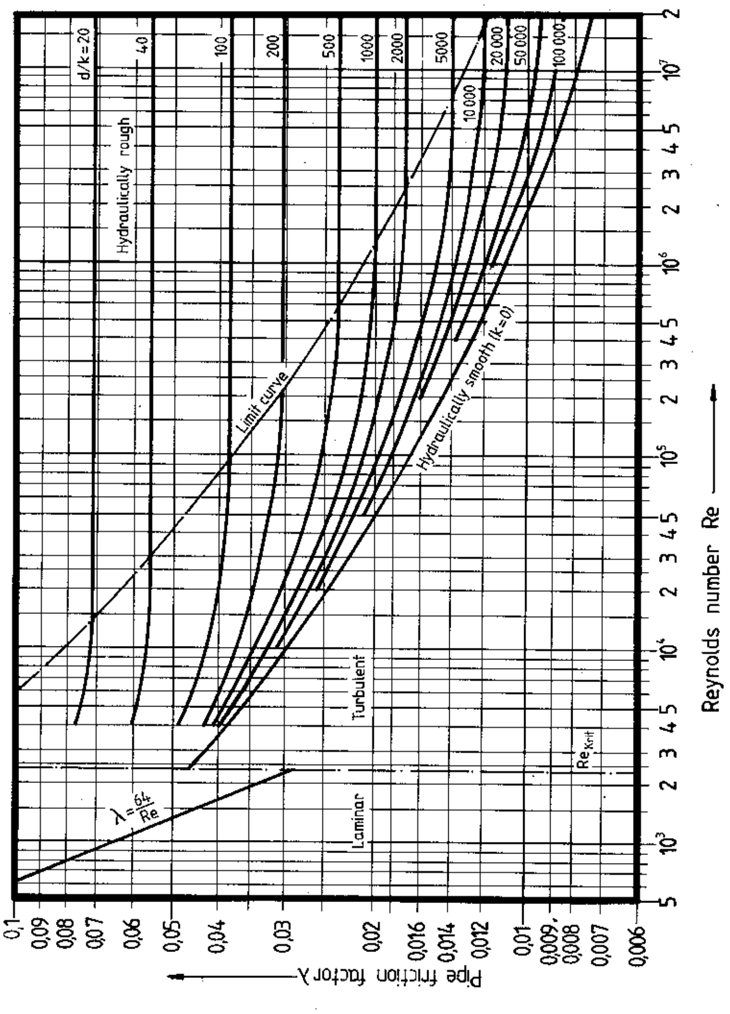
1 [lb/cft] = 16.02 [kg/m^3]; 1 [psia] = 0.069 [bar]

γ at 0 [°C], 1 [bar] from various sources:

Nr	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Equation	Cl_2	C_4H_{10}	C_3H_8	CO_2	F_2	O_2		N_2	C_2H_2	NH_3	CH_4		He	SO_2	H_2	Ar
[diagram]	3.0	2.4	1.9	1.7			1.4	1.2	1.0	0.75	0.66	0.52			0.08	
[Vogel]	3.17	2.64	1.97	1.95	1.67	1.41	1.27	1.23	1.15	0.76	0.71	0.50	0.18	0.15	0.09	1.76

Moody diagram

Model



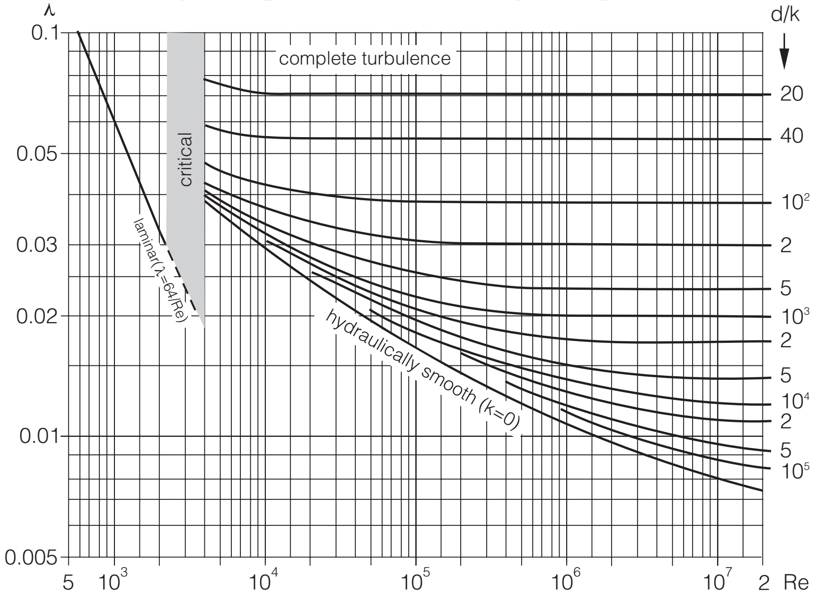
Example: Diameter d = 100 mm, roughness k = 0.1 mm ➥ d/k = 1000, Re = 42000 (4.2 · 10^4) ➥ pipe friction factor λ = 0.025

Remarks

Moody diagram - based on various sources.

New diagram

File fluidics-moody-en.eps; fluidics-moody-de.eps



Drawing time 9 h

Example DN = 100 [mm], pipe roughness k= 0.1 [mm] ➔ d/k = 1000; Re = 42000 ($4.2 \cdot 10^4$) ➔ pipe friction factor $\lambda = 0.025$.

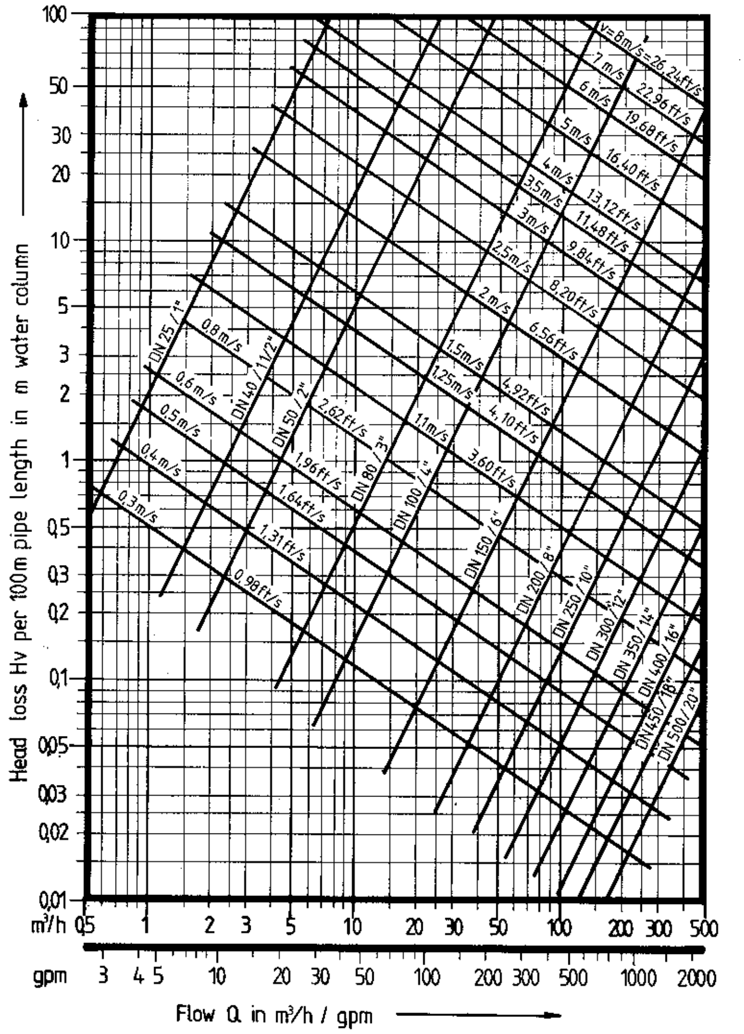
Equation See various sources, for example [Çengel].

Diagram data $e_\lambda = 53$; $e_{Re} = 20$; curves copied

Pressure losses in straight pipes DN 25 … 500

Prandtl-Colebrook diagram

Model



Example: *9 m³/h generates at DN 50 a flow velocity of v = 1.25 m/s and a loss over 100 m pipe H_V = 4.3 mWS (= 0.43 bar). DN 80, 9 m³/h ➡ v = 0.5 m/s ➡ H_V = 0.5 m/s ➡ H_V = 0.42 mWS (= 0.042 bar)*

Remarks

Dimension the US scale for 100 ft (rather than 300) ➔ Values are identical for H_V in [mWS/100m] and [ft water col./100ft].

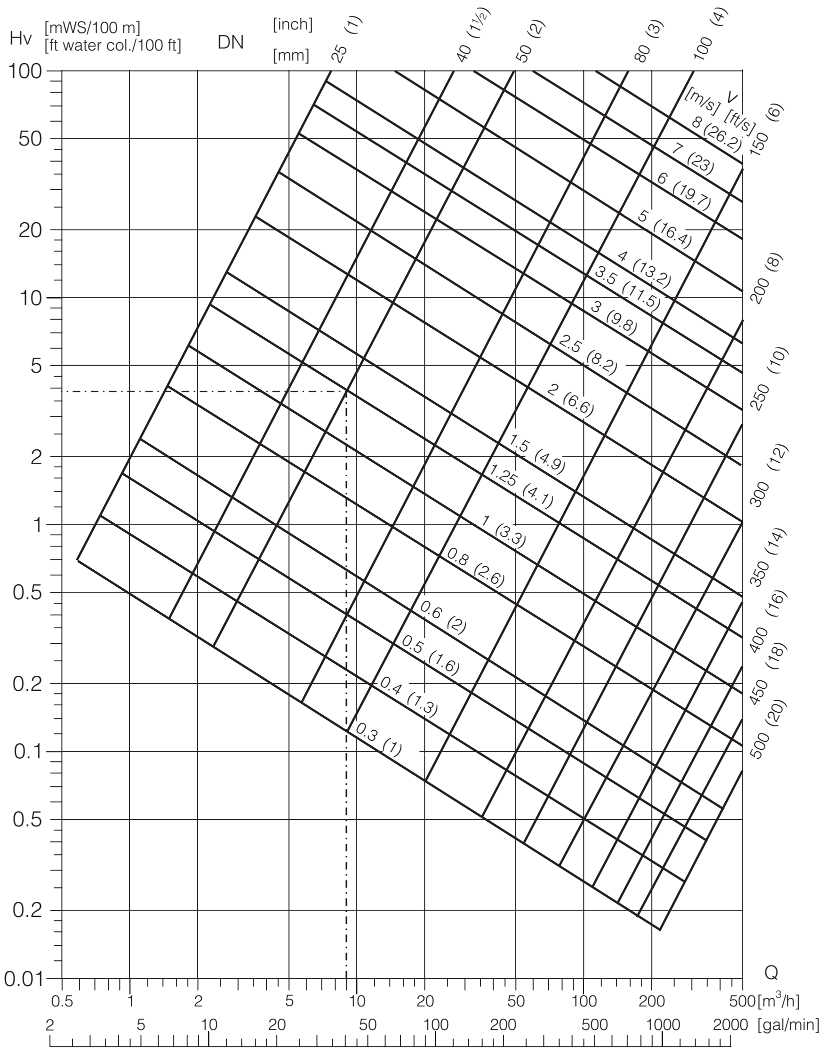
Keep the form, but leave out labelling at tight places.

An alignment chart Δp - Q - d - v (both Δp and v are results) would be possible, but the customer does not like it.

Note: *Diagrams are valid for k = 0.1 [mm]*

New diagram

File appendix-prandtl-colebrook-1.eps



Drawing time

4 h (includign checking fixed points)

Examples

A pumped flow of 9 [m^3/h] in a DN 50 pipe produces a flow velocity of 1.25 [m/s] and, over 100m of pipe, a pressure loss of H_V = 3.9 [m WC] = 0.39 [bar].

Q =40 [gal/min] generates at DN 50 a flow of v = 4.1 [ft/s] and a head loss over 100 [ft] pipe H_V = 3.9 [ft watercol.] = 0.11 [bar]

Equation

$\Delta p = \lambda \frac{l}{d}\frac{\rho}{2}v^2$ and $Q = \frac{d^2\pi}{4}v$. with λ and ρ being constant.

λ is f(Re), that in turn depends on d and v.

Diagram data

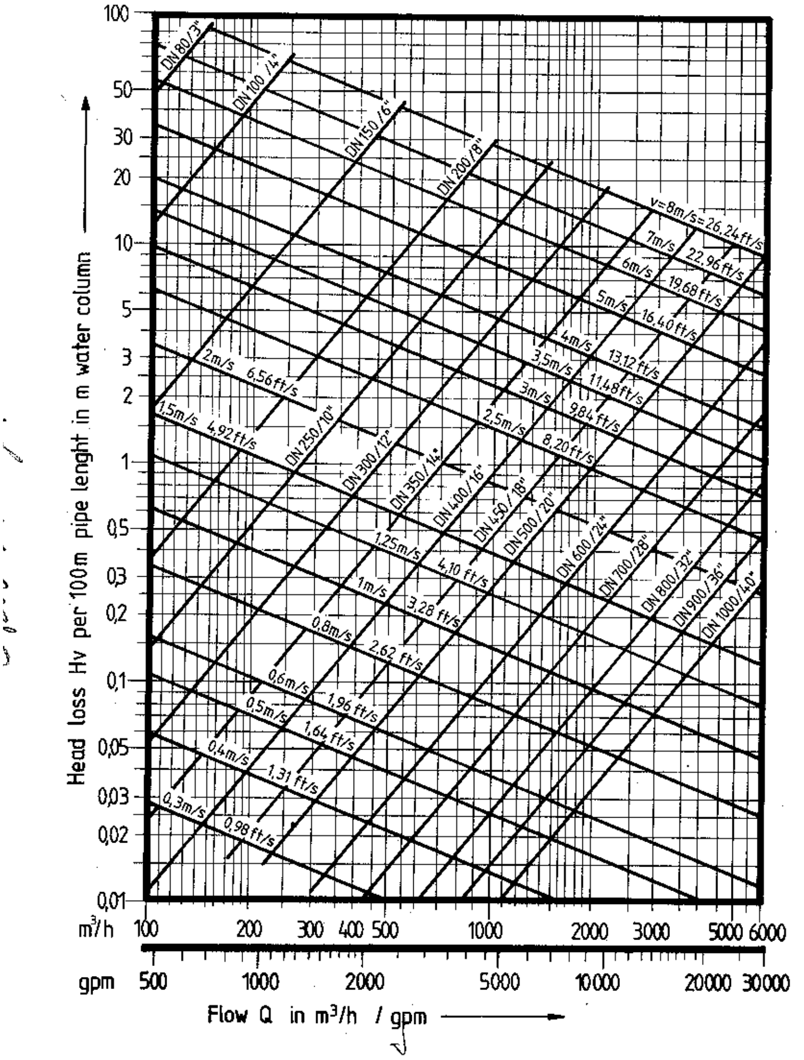
e_{Hv} = 30; e_Q = 30; straight linescopied (with $e_{DN} \approx 70$; $e_v \approx 65$). copied lines divert from log-scale up to mm ab. Since no reference points of Hv were available this could not be corrected.

Constants

1 USgal = 3.785 dm^3; 1 ft = 0.305 m; 1 [gal/min] ➔ 0.2271 [m^3/h]

Pressure losses in straight pipes DN 80 … 1000

Model



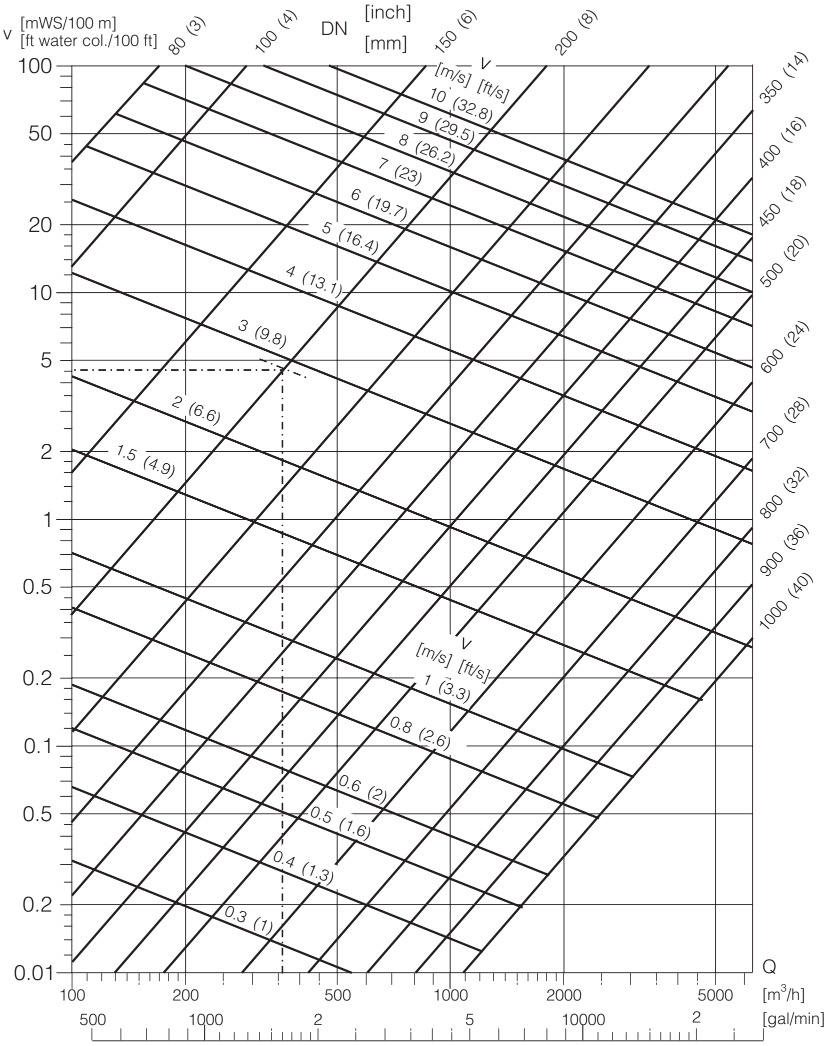
Example: *Q = 360 m³/h, DN 200 ➡ v = 3.2 m/s ➡ Loss Hv over 100 m pipe = 4.5 mWS (= 0.45 bar)*

Remarks

See diagram on page 34.

New diagram

File appendix-prandtl-colebrook-2.eps



Drawing time

4 h (incl. calculation of fix points)

Examples

Q = 360 [m^3/h] öroduces atDN 200 a flow volicity of 2.9 [m/s] and a pressure loss for 100 [m] pipe of 4.5 [m WS] = 0.45 [bar]

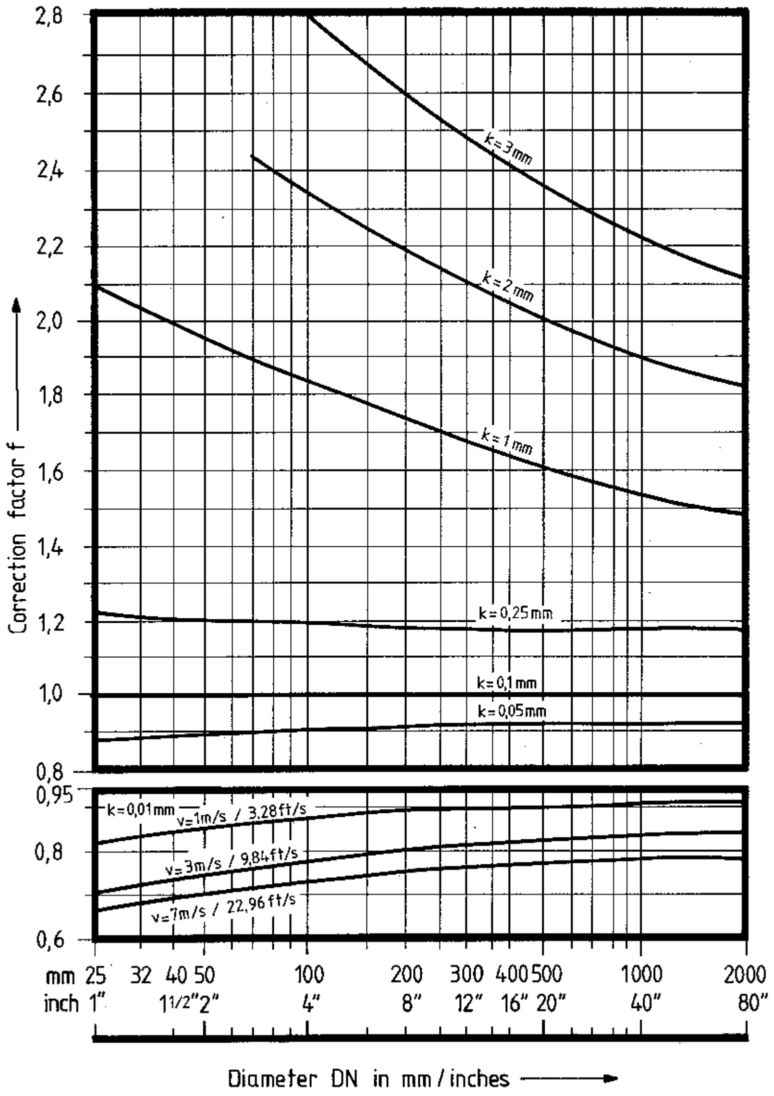
Q = 1585 [gal/min] produces at DN 200 a flow of v = 9.5 [ft/s] and a head loss over 100 [ft] pipe H_v = 4.5 [ft watercol.] = 0.14 [bar].

Diagram data

$e_{Hv} = 30$; $e_Q = 50$; straight lines copied (with $e_{DN} = 100$; $e_v = 72$). The copied lines fit well to the logarithmic scales.

Correction factors for pipe roughness values

Model



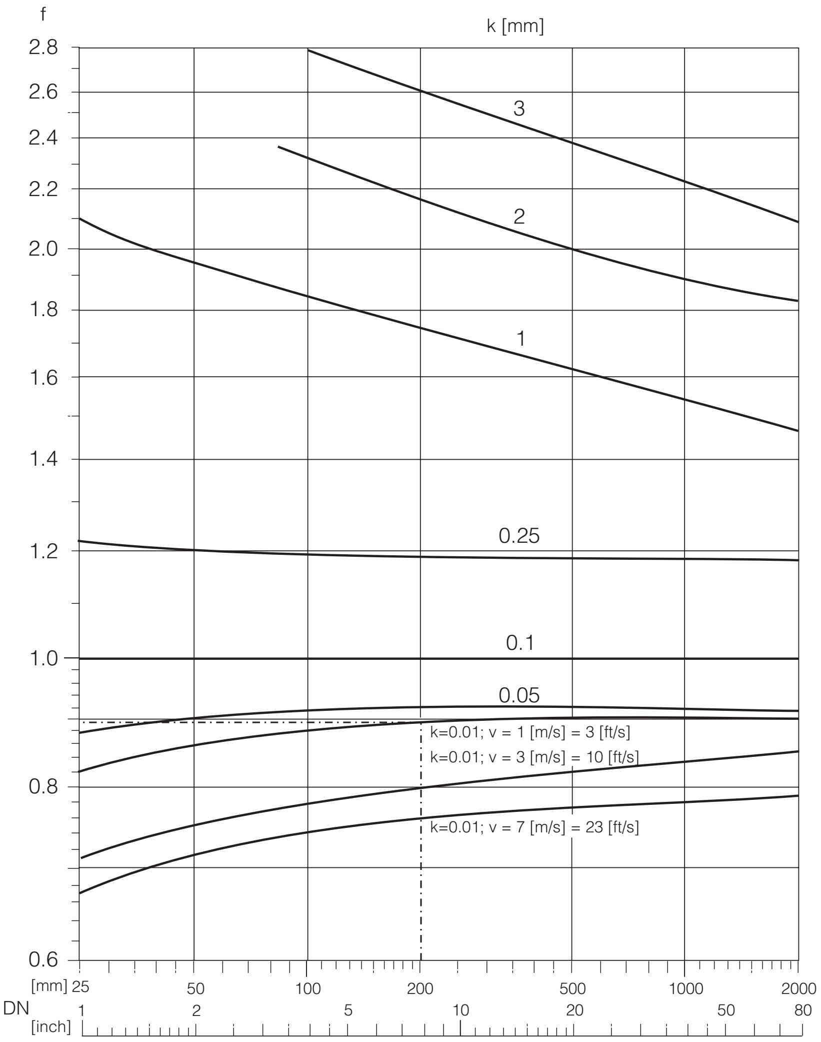
Example: *From table 25 $H_v = 4.5$ mWS at $k = 0.1$ mm, for $k = 0.05$, DN 200 ➡*
Correction factor $f = 0.91$. Therefore $H_v = 4.5 \cdot 0.91$ mWS.

Remarks

If possible add some k-values.

New diagram

File appendix-correct-roughness.eps



Drawing time

2.5 h

Example

From previous diagram: H_v =15 [ft water col.] at k=0.1 [mm]. For k = 0.05 and DN = 7.5 [inch] the correction factor f = 0.9. Hence the head loss (for 100 ft pipe) H_v = 4.5 * 0.9 = 4.05 [ft water col.].

Diagram data

e_f = 180; e_{DN} = 50; Data picked up from old diagram:

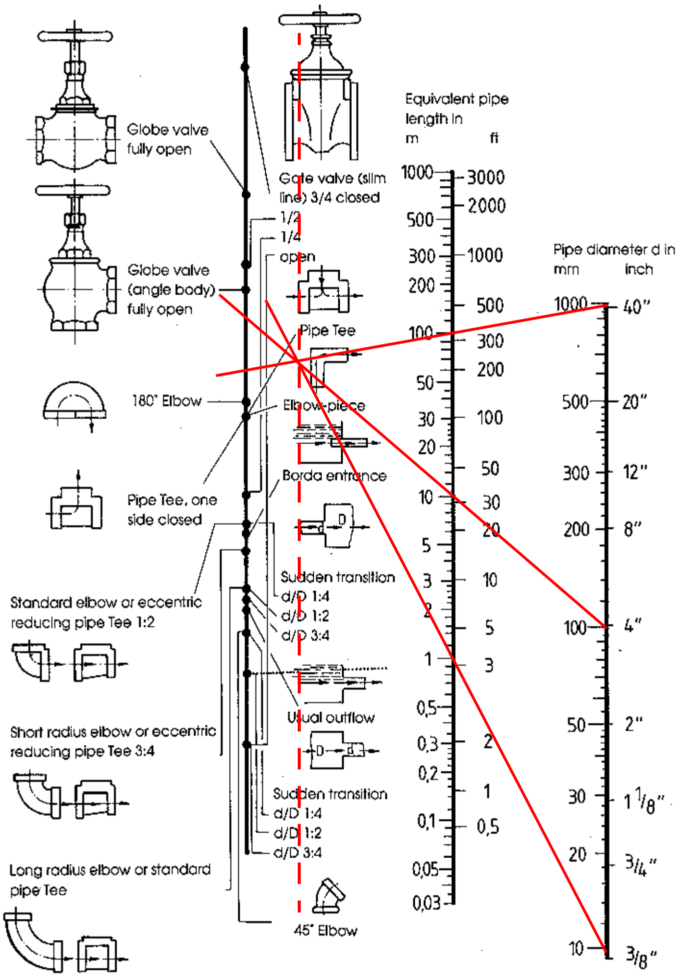
DN	k 3	2	1	0.25	0.1	0.05	0.01, v=1	0.01, v=3	0.01, v=7
25	-	-	2.10	1.22	1	0.88	0.82	0.71	0.67
100	2.8	2.34	1.84	1.20	1	0.91	0.88	0.78	0.74
1000	2.22	1.9	1.54	1.19	1	0.92	0.91	0.83	0.78
2000	2.12	1.83	1.39	1.18	1	0.92	0.91	0.84	0.79

Constants

1 USgal = 3.785 dm^3; 1 ft = 0.305 m; 1 [gal/min] ➔ 0.2271 [m^3/h]

Equivalent pipe lengths for various valves and fittings

Model



Example: Sudden change from D = 160 mm to d = 80 mm; d/D = 1:2
Dotted line ➡ l = 0.88 m (Pressure loss equivalent to 0.88 m straight pipe 80 mm diameter)

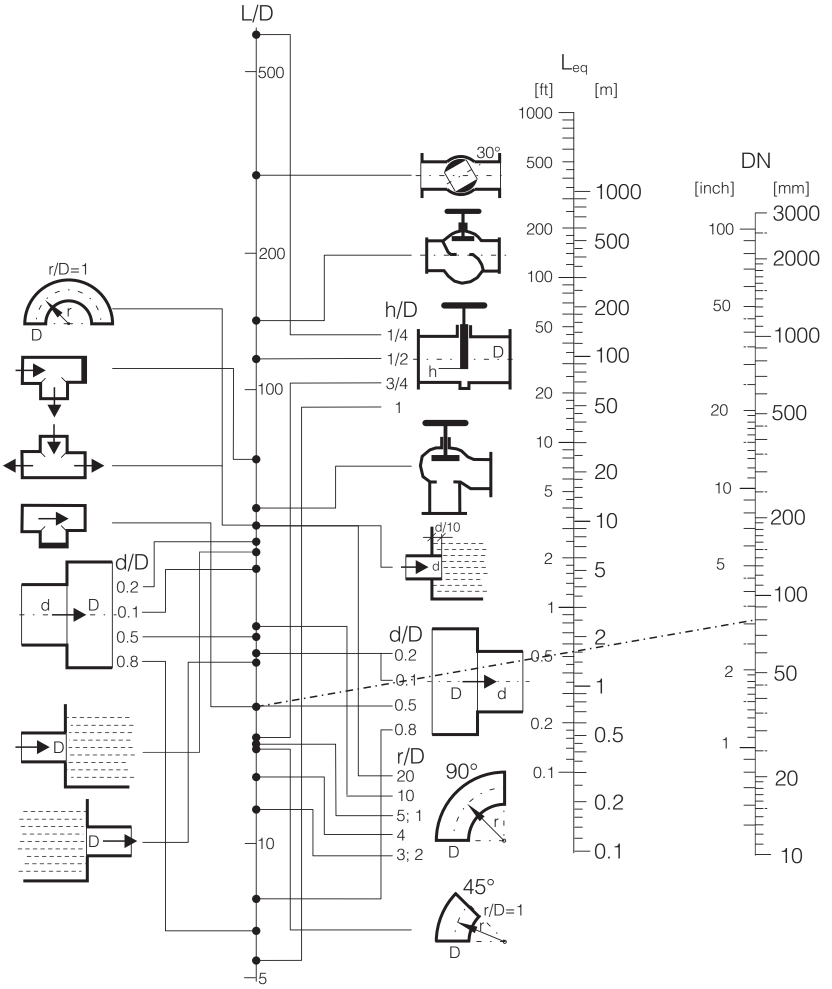
Remarks

Presumably valid for pipe roughness 0.02 … 0.05 mm (new steel pipe). The old diagram is completely wrong (see red lines). Nevertheless this wrong diagram is copied and copied …

[Sturmayr] The head loss coefficients can only be found by experiments. Notion of source is essential.

New diagram

File appendix-equivalent-fittings.eps



Drawing time

8.5 h + collection of data (7.5h)

Example

Sudden transition from D = 160 [mm] to d = 80 [mm] ➔ d/D = 0.5. The equivalent pipe length of diameter CN 80 is 1.6 [m].

Note: *For sudden transitions the results relate to the smaller diameter (d).*

Diagram data

$e_{L/D} = 60$; $a_{L/D\text{ - }DN} = 66$; $a_{L/D\text{ - }L} = 42$; $e_L = 21.81$; $e_{DN} = 34.28$
L/D-values according to [Crane] and others - harmonised.

Equation

Fittings: $\Delta p = \zeta \frac{\rho}{2} v^2$; pipes: $p = \lambda \frac{l}{d} \frac{\rho}{2} v$. $L = \frac{d\zeta}{\lambda}$; according to [Crane]: $\frac{L}{D} = \frac{K}{f_t}$; f_t = friction factor at turbulence. $\lambda = \frac{64}{Re}$;

$Re = \frac{vd}{\nu}$ (ν = kinematic viscosity). $\zeta = f$(d, construction etc.) ➔
ζ = K see sources.

Remarks

I have put together data from various sources in *Data for "equivalent pipe length"* on page 44. The values i used in the nomogram are part of these (mainly taken from [Crane] which most likely are based on a roughness of 0.1 mm).

Fitting	Specification	L/D	f_{turb}
angle valve		55	0.02
ball valve	30° closed	307	0.02
elbow 45° std	r/D = 1	16	0.028
elbow 90° [a]	r/D = 1	20	0.018
elbow 90°	r/D = 2	12	0.018
elbow 90°	r/D = 3	12	
elbow 90°	r/D = 4	14	
elbow 90°	r/D = 5	16.5	0.018
elbow 90°	r/D = 10	30	0.018
elbow 90°	r/D = 20	50	0.018
elbow 180° (return bend)	r/D = 1	50	0.017
gate valve	25%open	555	0.028
gate valve	50%open	117	0.018
gate valve	75%open	16.7	0.018
gate valve	fully open	5.5	0.018
globe valve	fully open	142	0.028
globe valve (angle body)	fully open	117	0.018
pipe entrance	projecting 0.1d	44	0.018
pipe entrance	sharp	25	0.028
pipe exit	sharp	50	0.02
sudden transition d➔D	d/D = 0.1	40	0.02
sudden transition d➔D	d/D = 0.2	46	0.02
sudden transition d➔D	d/D = 0.5	28	0.02
sudden transition d➔D	d/D = 0.8	6.5	0.02
sudden transition D➔d	d/D = 0.1	26	0.02
sudden transition D➔d	d/D = 0.2	26	0.02
sudden transition D➔d	d/D = 0.5	20	0.02
sudden transition D➔d	d/D = 0.8	7.5	0.02
tee, std	branch flow	60 - 75	0.018
tee, std	branch to runs	50	
tee, std	thrugh flow	20	0.01

[a] The L/D values decrease with increasing r/D, starting with r/D = 2.5 they increase again. I can not explain this, but have found this behaviour in all sources.

Terminiology

English	German
angle valve	eckventil
ball valve	kugelhahn, kugelventil
butterfly valve	drossel-klappe, -ventil, absperrklappe
check valve	rückschlag-ventil, -klappe
foot valve	bodenventil, fussventil, saugkorb-ventil
gate valve	(absperr-)schieber
globe valve	durchgangsventil, absperrventil
lift check valve	rückschlag-ventil
mitred bends, mitred elbows	geschweisste eckstücke
plug valve	kükenhahn, zapfhahn
return bend	U-bogen
swing check valve	rückschlag-klappe
throttle valve	rückschlag-klappe

Data for “equivalent pipe length”

Most data is from [Crane], few from Georg Fischer UK (web). Values in the shaded areas have been calculated from the other given data according to $\frac{L}{D} = \frac{K}{f_t}$. If f_t is not given, I have assumed 0.02.The data of [Crane] are based on f_t = 0.018.

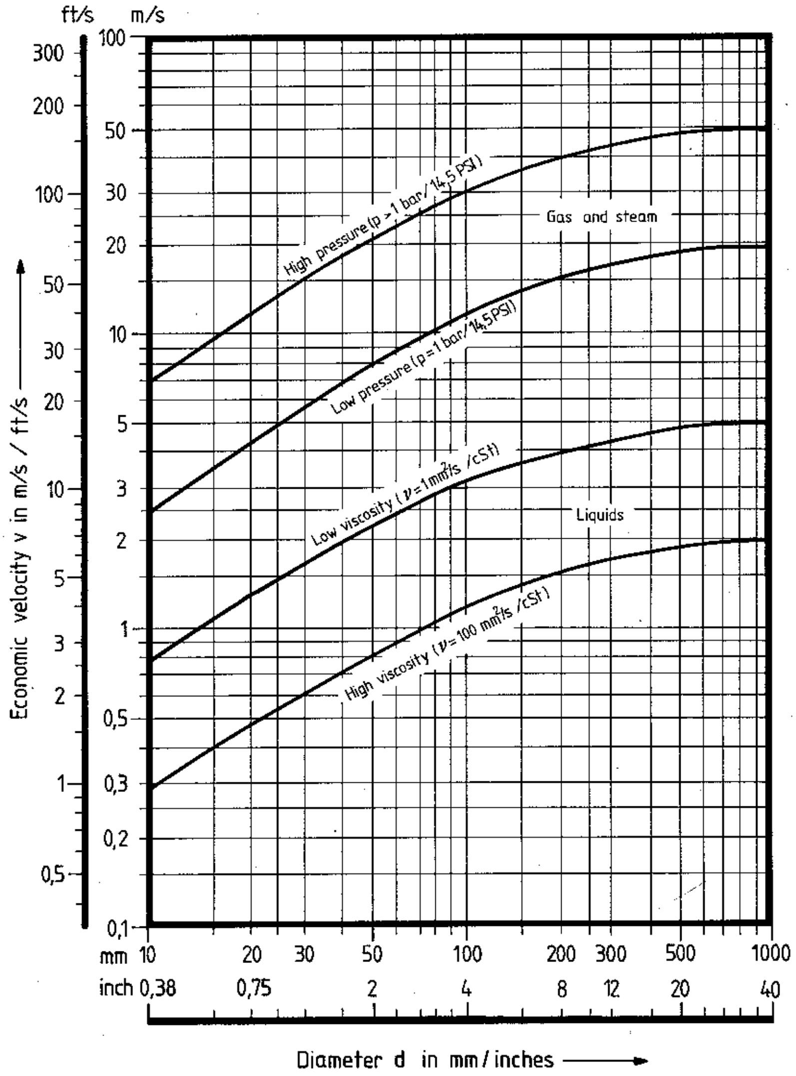
		Old diagram	program Pressure-Drop v5	[Crane] and others		
Fitting	**Specification**	**L/D**	**ζ**	**L/D**	**K = ζ**	**f_{turb}**
angle valve				55	1.1	0.02
angle valve	wide open	118	4 - 6.5	150	5	0.018
ball valve	full bore (open)			3	0.06	0.02
ball valve	30° closed		6.15	307	6.15 3)	0.02
ball valve	45° closed		58	3000	60 3)	0.02
ball valve	50° closed			5750	95 3)	0.02
bend 45°			0.48	20	0.40	0.02
bend 90°	r/d = 1		0.21	20	0.36	0.018
bend 90°	r/d = 10			30	0.54	0.018
bend 90°	r/d = 2		0.14	12	0.22	0.018
bend 90°	r/d = 20			50	0.90	0.018
bend 90°	r/d= 5		0.1	16.5	0.30	0.018
butterfly valve				43	0.86	0.02
check valve	tilting disk			5 - 15	0.1 - 0.3	0.02
concentric reducer d→D	d/D = 0.9			1.45	0.026	0.018
concentric reducer d→D	d/D =0.50			27.8	0.5	0.018
concentric reducer d→D	d/D =0.67			15.6	0.28	0.018
concentric reducer D→d	d/D =0,9			0.44	0.008	0.018
concentric reducer D→d	d/D =0.50			8.9	0.16	0.018
concentric reducer D→d	d/D =0.67			4.7	0.085	0.018
concentric reducer d→D	d/D =0.75			8.9	0.16	0.018
concentric reducer d→D	d/D =0.8			5.6	0.13	0.018
concentric reducer D→d	d/D =0.75			2.7	0.049	0.018
concentric reducer D→d	d/D =0.8			2.3	0.041	0.018
elbow long R	90°			16 - 20	0.36	0.018
elbow, long radius	90°, R/d = 3	21		15		
elbow, short radius	90°, R/d = 4	26		22		
elbow, std	45°	3.2		16	0.42	0.028
elbow, std	90°	30		30	0.9 3)	0.028
gate valve	25%open	420	22.5	555	8 - 13	0.028
gate valve	50%open	135	2.06	117	2.1	0.018
gate valve	75%open	36	0.305	16.7	0.3	0.018
gate valve	fully open	8.5		5.5	0.1	0.018
globe valve	fully open	200		142	4	0.028
globe valve (angle body)	fully open	117		117	2.1	0.018
lift check valve				55 - 600	1.1 - 12	0.02

		Old diagram	program Pressure-Drop v5	[Crane] and others		
Fitting	**Specification**	**L/D**	**ζ**	**L/D**	**K = ζ**	**f_{turb}**
mitred bend	15°			4	0.07	0.018
mitred bend	30°			8	0.14	0.018
mitred bend	45°			15	0.27	0.018
mitred bend	60°			25	0.45	0.018
mitred bend	90°			60	1.08	0.018
mitred bend	0°			2	0.04	0.018
pipe entrance	projecting 0.1d	28	3	44	0.8	0.018
pipe entrance	rounded			1.5	0.03	0.028
pipe entrance	sharp		0.5	18 - 28.5	0.5 - 0.8 3)	0.028
pipe exit	sharp	18		50	1 3)	0.02
plug valve	branch flow			90	1.8	0.02
plug valve	straight flow			18	0.32	0.018
plug valve 3 way	through flow			30	2.2	0.028
pump foot valve				54	1.5	0.028
pump foot valve	hinged disk			75	1.5	0.02
pump foot valve	poppet disk			420	8.4	0.02
return bend	r = D	62		50	0.85	0.017
sudden transition d→D	d/D = 0.1			40	0.98	0.02
sudden transition d→D	d/D = 0.2	30		46	0.92	0.02
sudden transition d→D	d/D = 0.5	21	9	28	0.56	0.02
sudden transition d→D	d/D = 0.8	20		6.5	0.13	0.02
sudden transition D→d	d/D = 0.1			26	0.52	0.02
sudden transition D→d	d/D = 0.2	16		26	0.52	0.02
sudden transition D→d	d/D = 0.5	13	0.4	20	0.40	0.02
sudden transition D→d	d/D = 0.8	8.5		7.5	0.15	0.02
swing check valve			1.3 - 2	50 - 100	0.9	0.018
tee, std	branch flow	56	0.7 - 1.3	60 - 75	1.08	0.018
tee, std	branch to runs	58		50	1.5	
tee, std	through flow			20	0.2	0.01
throttle valve (disk)	30° closed		3.91	195	3.91 3)	
throttle valve (disk)	45° closed		21.7	1100	22 3)	0.02
throttle valve (disk)	60° closed		118	immense	118 3)	0.02
throttle valve (disk)	70° closed		250	immense	250 3)	0.02

Note: *For the transitions (sudden, gradual) the L/D-values are for the smaller diameter.*

Economical flow velocityn

Model



Example: *For liquids* $\nu = 10^{-6}\ m^2/s$ *(= 1 cSt) at DN 100 v = 3 m/s is ideal flow velocity.*
For gas p = 1 bar at DN 100 ideal flow velocity is v = 12 m/s.

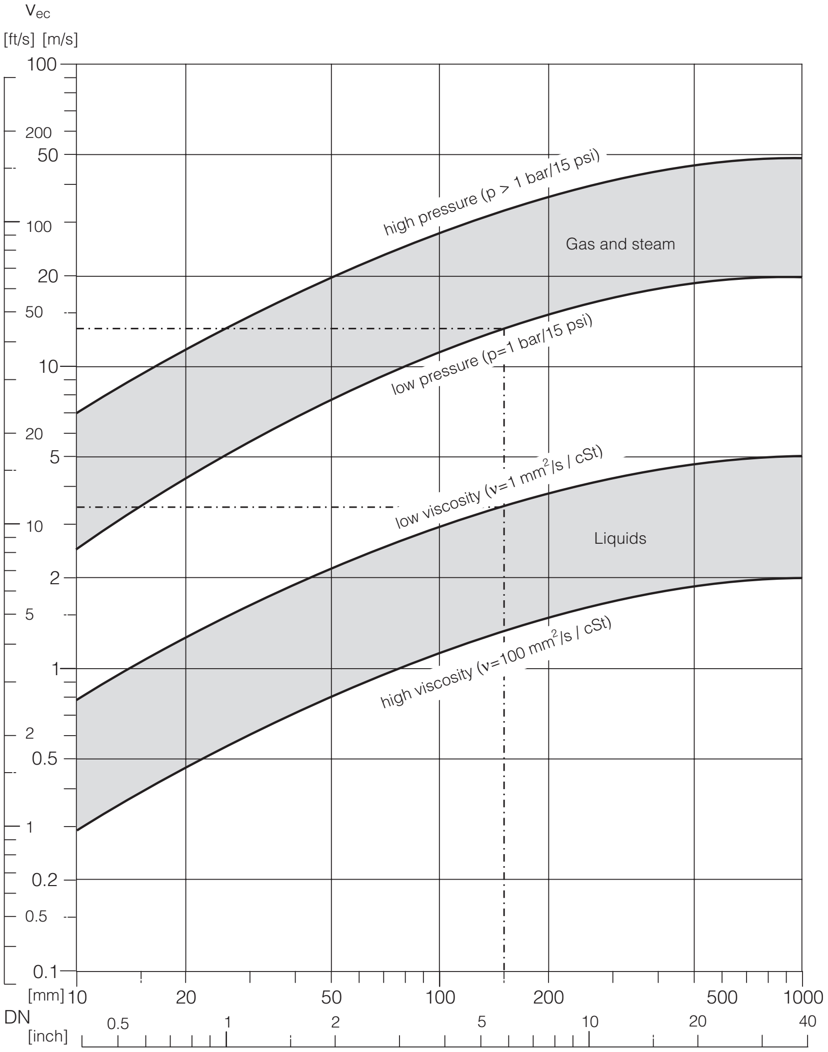
Remarks

The old diagram is misleading (see new labelling and presentation).

[Sturmayr] I haven’t seen such diagrams until now. The curves seem to indicate the area of turbulence (laminar flow most time is to slow). The curves may not strictly follow fluid mechanical criteria, but consider some cost functions. Hence the curves may be very approximate.

New diagram

File appendix-economic-velocity-de.eps;
appendix-economic-velocity-en.eps



Drawing time

1.5 h

Example

For liquids having a viscosity of $\nu = 1$ [cSt = 1 mm^2/s] and a pipe nominal diameter DN = 150 [mm] the ideal flow velocity is v = 3.4 [m/s].

For gases at a pressure of 1 [bar] flowing in a pipe of nominal diameter DN = 150 [mm], ideal flow velocity is v = 13.5 [m/s].

Equation

“Economical” indicates some hidden assumptions. Hence I can only copy the diagram.

Diagram data

$e_{DN} = 48$; $e_v = 40$; curves copied

Constants

1 ft = 0.305 m

Compressibility factor Z

Model

Don’t have the relevant scan anymore. The following has a completely different range

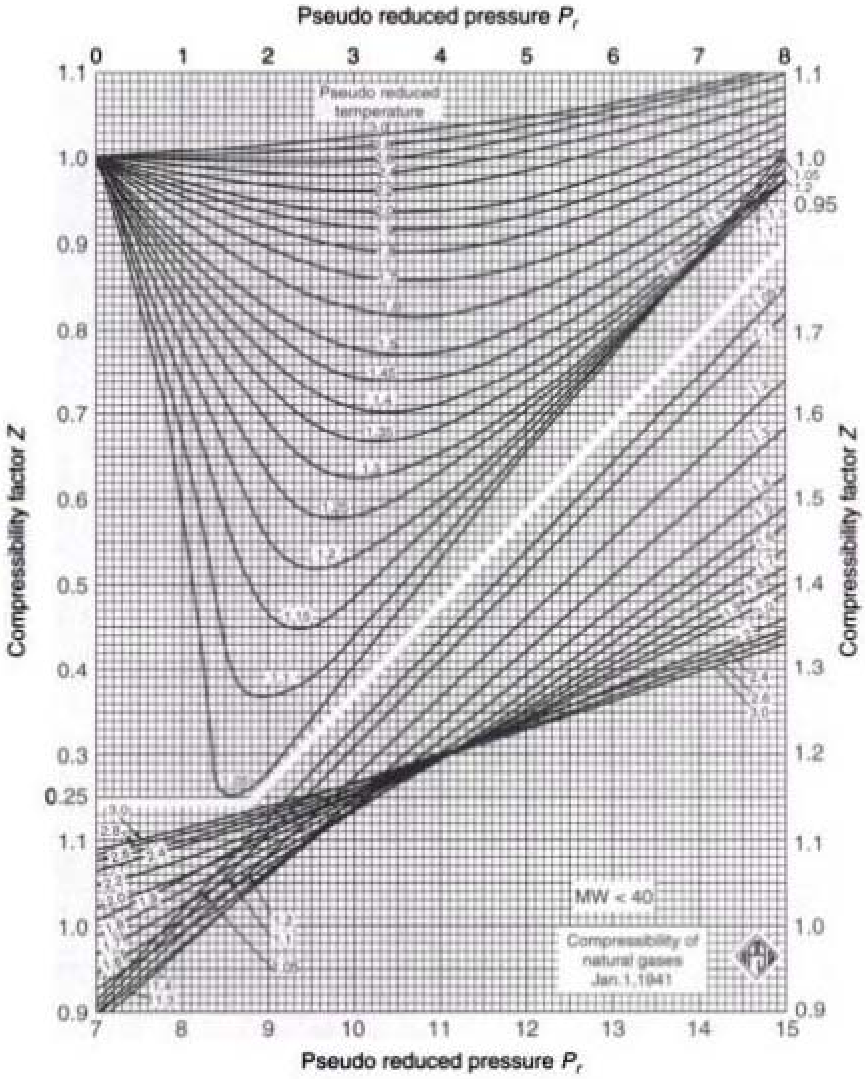
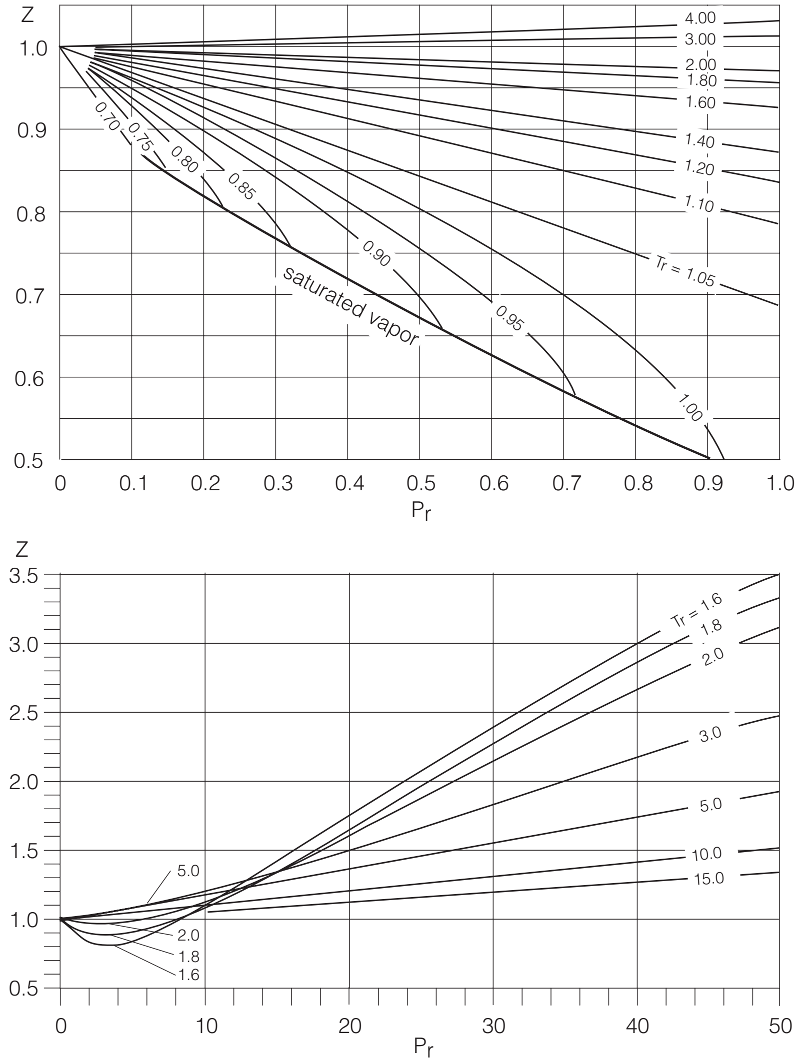


Figure 9.10 Compressibility factor. (Reproduced with permission from Gas Processors Association, *Engineering Data Book*, vol. II, Tulsa, Oklahoma, 1994.)

This drawing appears in many books

New diagram

File Fluidics-Compress-Gas-en.eps



Drawing time 5.00

Remark

The reduced temperature T_r is the temperature of the gas divided by its critical temperature. The reduced pressure P_r is the pressure of the gas divided by its critical pressure.

For example N_2 has a critical temperature of -147 ˚C and a critical pressure of 34 bar. If the gas temperature and pressure are 38 ˚C and 13.8 bar, then

$$T_r = \frac{38 + 273}{-147 + 273} = 2.46 \quad P_r = \frac{13.8}{34} = 0.406$$

The actual behaviour of most gases is accounted for by the introduction of a compessibilty factor Z. The equation of state for ideal gases then becomes:
P V = Z n R T
(with R the gas constant, n the molecular weight).

The compressibility factor Z is the ratio of the real gas volume to the volume occupied by the same mass of an ideal gas at the same temperature and pressure.

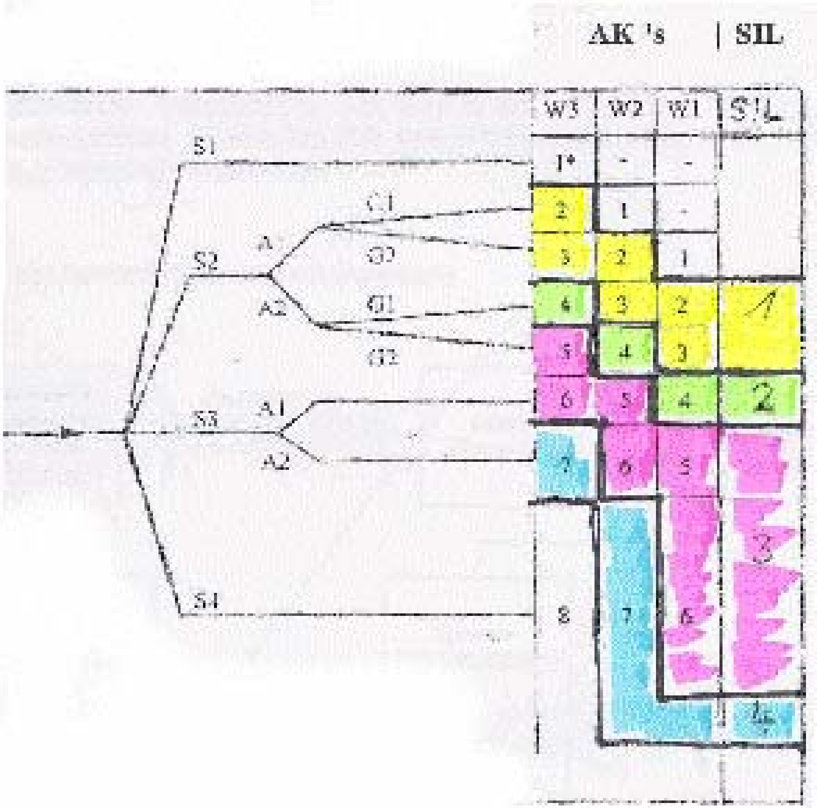
[Piping Calculations Manual By E. Shashi Menon, ISBN 9780071440905]

See also [Çengel] “Comparison of Z factor for various gases”

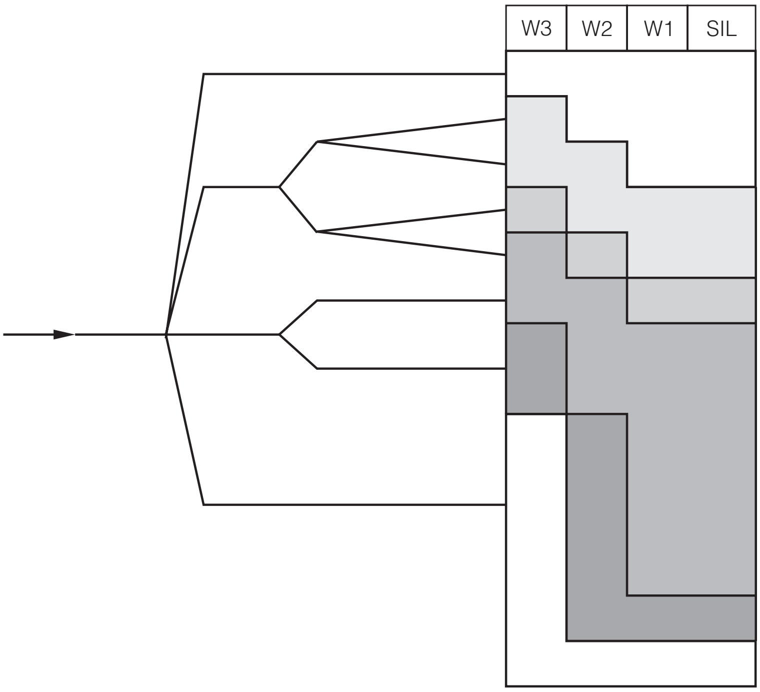
Other drawings

These are some diagrams I drew for the Flow Handbook.
There are many more in this book drawn by another person.

SIL risk chart



File guidelines-sil-riskchart.eps



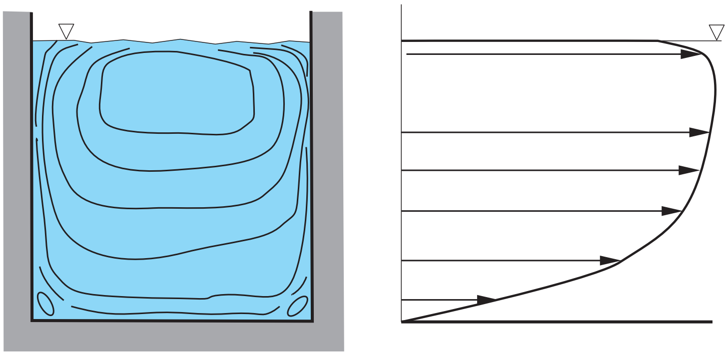
Drawing time 3.0 h

2008-09-18

E:\Flowtec\Flow-Handbook\diagrams-commented.fm

Open channel measurement

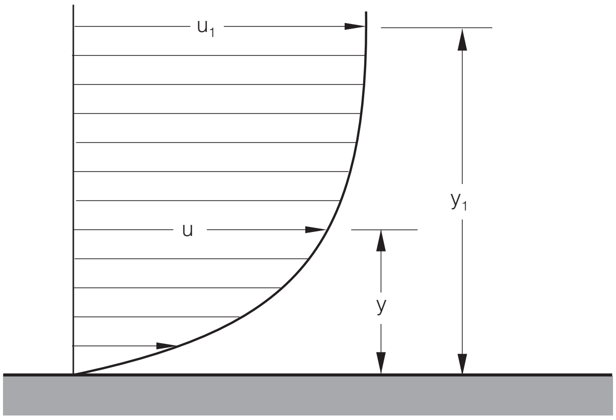
File Fluidics-Openchannel.eps



Drawing time 3.00

Fluidics-viscosity

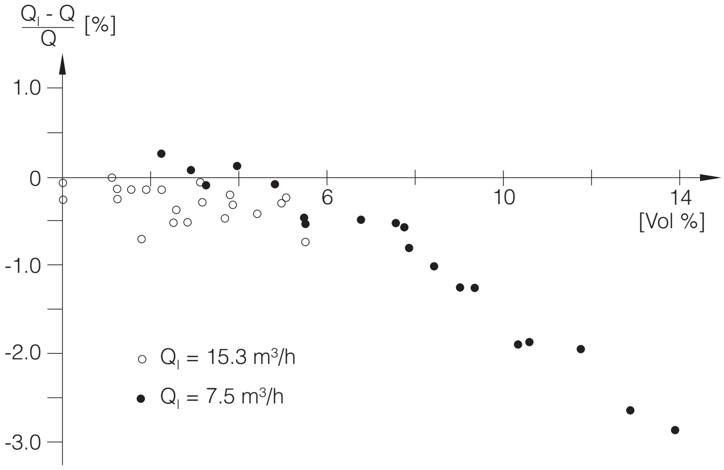
File Fluidics-Viscosity.eps



Drawing time 2.00

Measurement error with two phase medium

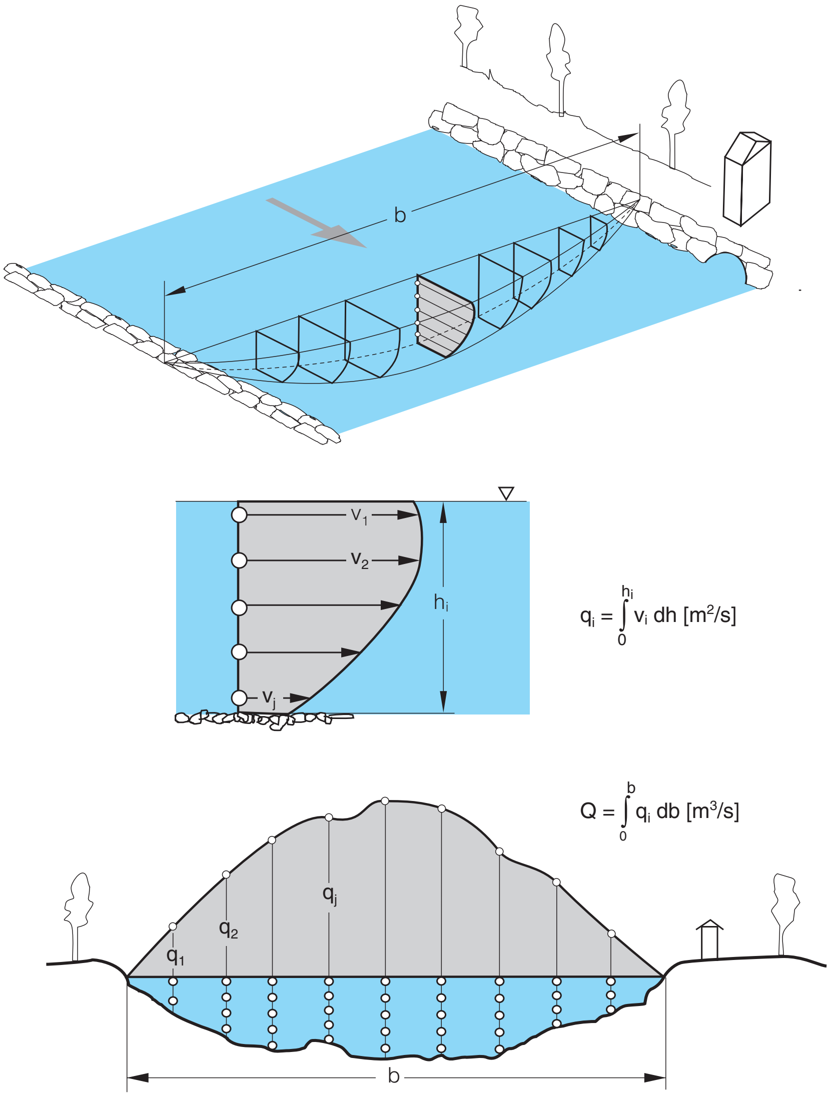
File Installation-Two-Phase.eps



Drawing time 2.00

Measuring principle of the velocity-area method

File Principles-OPEN-Velocity-area.eps



Drawing time 12.00

Tools used for the diagrams

On demand of the contractor I used Corel Draw version 8 (although at that time version 10 was current) for the diagrams.

The various scales however were not developed in Corel, but are copies from my own work (see Clip art for diagrams and nomographs).

These scales had been drawn in FrameMaker and saved as PDF which allows to handle them in various graphic packages. The drawing in FM was performed with a special WinBatch script:

1 In an anchored frame insert a short line with the desired properties (colour, width, type) and leave it selected (that is as the current object).

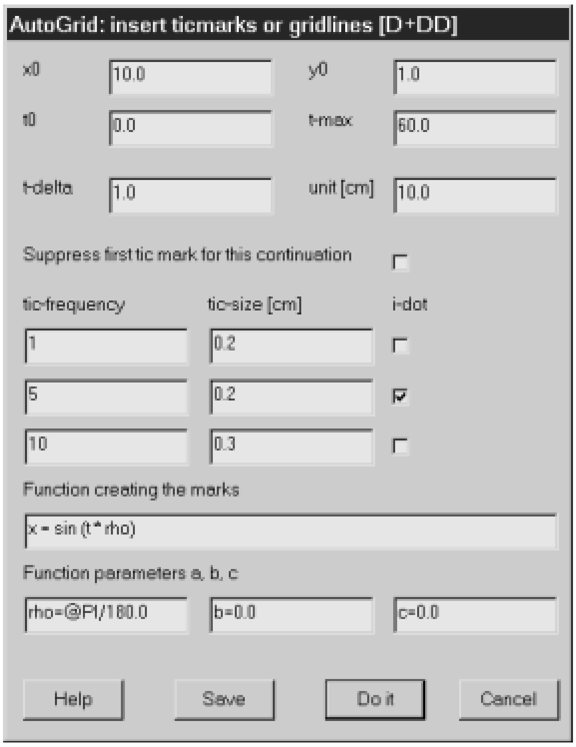
2 In the utility AutoGrid specify the necessary parameters to draw a scale.

3 AutoGrid modifies the properties of the object (coordinates, size) to place the first tic mark.

4 If the 'end' condition for the scale is not yet met, a copy of this object is created and step 3 is repeated.

5 The user then groups the generated tic marks to avoid accidental modification, adds a spine line and labelling.

Appearance of AutoGrid



AutoGrid: insert ticmarks or gridlines [D+DD]

x0	10.0	y0	1.0
t0	0.0	t-max	60.0
t-delta	1.0	unit [cm]	10.0

Suppress first tic mark for this continuation ☐

tic-frequency	tic-size [cm]	i-dot
1	0.2	☐
5	0.2	☑
10	0.3	☐

Function creating the marks

x = sin (t * rho)

Function parameters a, b, c

rho=@PI/180.0 | b=0.0 | c=0.0

Coordinates in the frame

This figure does not relate to the screen shot above.