Hydraulic Design Of Polyethylene Pipes

Waters & Farr polyethylene pipes offer a hydraulically smooth bore that provides excellent flow characteristics. Other advantages of polyethylene pipes, like inert, corrosion free pipe material, excellent toughness and abrasion resistance, help to maintain pipes' smooth bore throughout their service life.

Waters & Farr polyethylene pipes for pressure applications are manufactured to AS/NZS 4130. Series 1 pipes for conveyance of fluids (including potable water, storm- and waste water; excluding fuel gas) are designated by nominal outside diameter, **DN**.

Flow of fluids in a pipe is a subject to resistance due to viscous shear stresses within the fluid and friction against the pipe wall, resulting in a pressure loss. A number of formulae, both theoretical and empirical, were developed for fluid flow calculation and for creation of flow charts. The rate of flow is governed by pipe's inside diameter, *D*; latter tolerance for Series 1 pipes of each *SDR* (standard dimension ratio) is specified in AS/NZS 4130. As an approximate value for flow calculations only, inside diameter may be taken as:

$$D = \mathrm{DN} - 2.12 \times \left(\frac{\mathrm{DN}}{\mathrm{SDR}}\right). \qquad \text{(HD-1)}$$

The **Colebrook-White formula** for the velocity of water in a smooth bore pipe under laminar conditions takes the form:

$$V = -2 \times \sqrt{2gDJ} \times \log\left\{\frac{k}{3.7D} + \frac{2.51\nu}{D \times \sqrt{2gDJ}}\right\}, \qquad \text{(HD-2)}$$

where
- V – average flow velocity, m/s,
- k – Colebrook-White roughness coefficient, mm; for polyethylene pipes, the range of k is 0.003-0.015 for water and stormwater applications, k = 0.6 for wastewater applications (NZS 4404),
- D – mean inside diameter of pipe, m,
- J – hydraulic gradient (slope), m/m,
- ν – kinematic viscosity, m²/s; a value of 1.141×10^{-6} m²/s may be assumed for water at 15°C,
- g – gravitational acceleration; $g = 9.807$ m/s² may be assumed.

Flow (discharge), *Q*, l/s:

$$Q = \frac{\pi \times D^2}{4} \times V \times 10^3. \qquad \text{(HD-3)}$$

Design flow charts for polyethylene pipes based on the above formula for k = 0.015 mm are given for pipes to AS/NZS 4130 (minimum pipe inside diameter used) in Figures 1 to 15 and for Waters & Farr rural LDPE pressure pipes (average pipe inside diameter used) in Fig. 16.

Within transition zone between laminar and full turbulent flow, as is the likely case for most pipe applications, the **Colebrook formula** applies:

$$\frac{1}{\sqrt{f}} = -2 \times \log\left\{\frac{k}{3.7D} + \frac{2.51\nu}{\mathrm{Re} \times \sqrt{f}}\right\}, \qquad \text{(HD-4)}$$

where
- k – linear measure of roughness, mm,
- Re – Reynolds number, dimensionless: $\mathrm{Re} = \frac{V \times D}{\nu}$, (HD-5)
- f – friction factor, dimensionless, dependent upon surface roughness and Reynolds number;

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for laminar flow ($Re < 2000$): $f = \dfrac{64}{\mathrm{Re}}$. (HD-6)

The **Manning formula** for smooth bore pipe running full of water may be written in form:

$$V = \frac{1}{n} \times R^{2/3} \times J^{1/2}, \text{ or} \qquad \text{(HD-7)}$$

$$V = \frac{0.3950}{n} \times D^{0.67} \times J^{0.5} \text{ for circular pipes (AS 2200)} \qquad \text{(HD-8)}$$

where n – Manning roughness coefficient, dimensionless; for polyethylene pipes, the range of n is 0.008-0.009 for water and stormwater applications, 0.009-0.011 for wastewater applications (NZS 4404),

R – hydraulic radius, m:

$$R = \frac{A}{P}, \text{ or } R = \frac{D}{4} \text{ for circular pipes,} \qquad \text{(HD-9)}$$

A – flow cross-sectional area, m²,

P – wetted perimeter, m.

Design charts for hydraulic design of pipes using Manning formula are given in AS 2200 (see Fig. 17 displaying Chart 12 of the standard) and other literature.

ISO/TR 10501:1993 provides the following formulae for calculation of head drop (J).

The head drop for water at a temperature of 20°C, J_o, m/m:

for $4 \times 10^3 \le Re < 1.5 \times 10^5$, $J_o = 5.37 \times 10^{-4} \times (D^{-1.24} \times V^{1.76})$, (HD-10)

for $1.5 \times 10^5 \le Re \le 1 \times 10^6$, $J_o = 5.79 \times 10^{-4} \times (D^{-1.20} \times V^{1.80})$. (HD-11)

The head drop for water at a temperature different from 20°C, J_t, m/m:

$J_t = K_t \times J_o$. (HD-12)

where K_t – temperature correction factor, dimensionless, – values given in the table to the right should be taken.

Temp., °C	K_t: $4 \times 10^3 \le Re < 1.5 \times 10^5$	K_t: $1.5 \times 10^5 \le Re \le 1 \times 10^6$
0	1.148	1.122
5	1.105	1.087
10	1.067	1.055
15	1.033	1.027
20	1.000	1.000
25	0.972	0.977
30	0.947	0.956
35	0.925	0.937
40	0.904	0.919
45	0.885	0.903

For a liquid other than water at 20°C, the head drop, J_x, m/m:

$$J_x = J_0 \times \left(\frac{\nu_x}{\nu_w}\right)^b, \qquad \text{(HD-13)}$$

where ν_x – kinematic viscosity of the liquid, m²/s,

ν_w – kinematic viscosity of water at 20°C, m²/s,

b – exponent dependent upon Reynolds number:

for $4 \times 10^3 \le Re < 1.5 \times 10^5$, $b = 0.24$,

for $1.5 \times 10^5 \le Re \le 1 \times 10^6$, $b = 0.20$.

Head loss H, m, for a pipe of a length L, m, may be calculated as follows:

$H = J \times L$. (HD-14)

Changes in elevation provide for losses or gains in line pressure and have to be taken into account in hydraulic calculations. For liquids, the pressure loss (or gain) for a given elevation change may be calculated as follows:

$$H_E = h_1 - h_2 \, , \tag{HD-15}$$

Where H_E – elevation head loss, m,
h_1 – pipeline elevation at point 1, m,
h_2 – pipeline elevation at point 2, m.

The elevation points may be taken at the ends of the pipeline in case of uniform elevation change, or at the ends of each section of the pipeline that is a subject to uniform elevation change in case of several elevation changes (overall elevation head loss is then calculated by summing the sectional head losses).

If a pipeline has a high point significantly elevated in relation to both ends, accumulation of air or vacuum at the high point will affect the flow in the line (or lead to vacuum collapse of the pipe). Where such events are possible, appropriate vents should be incorporated in the pipeline design to prevent their occurrence.

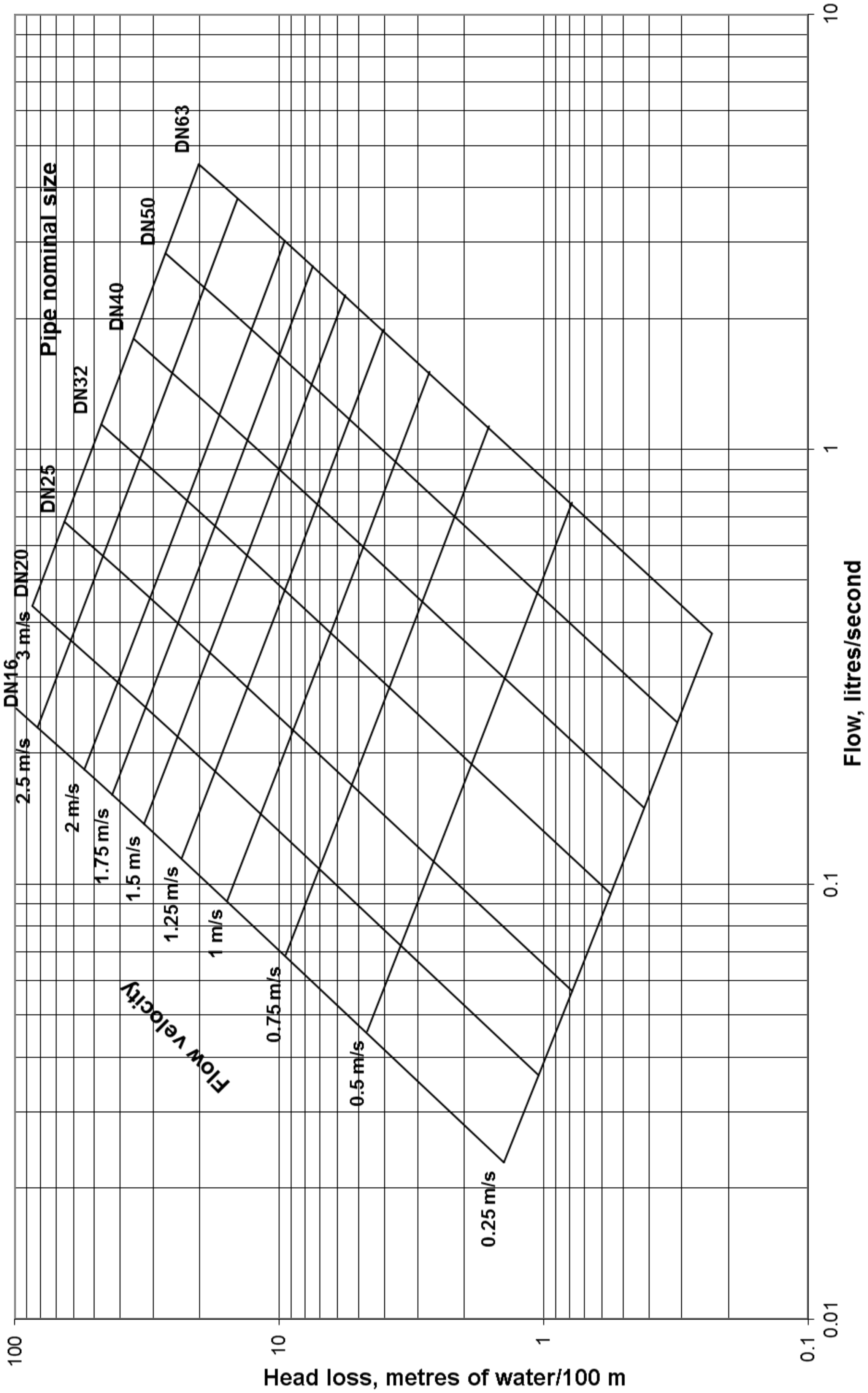


Fig. 1. Colebrook-White friction loss chart for DN16 – DN63 SDR 7.4 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

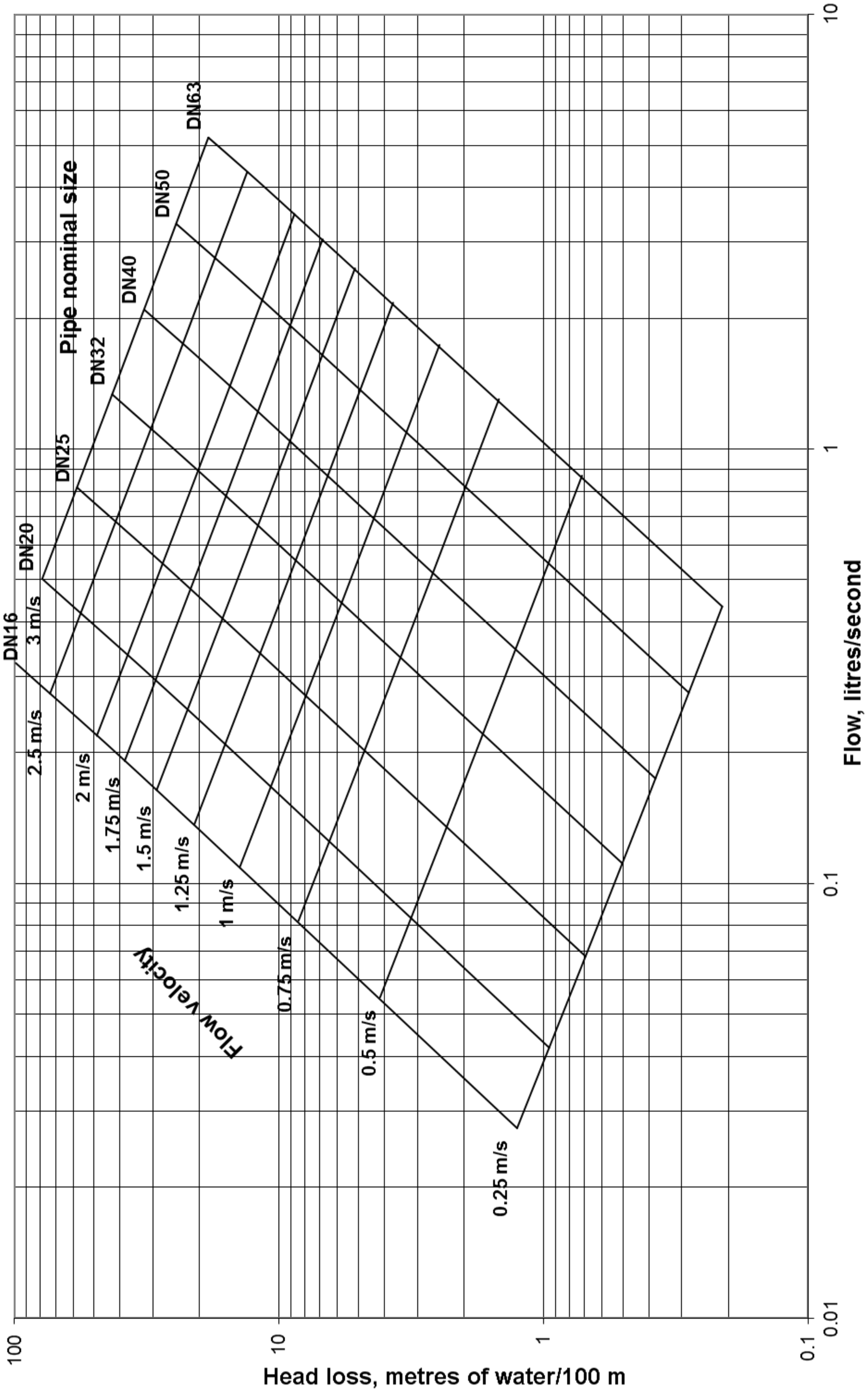


Fig. 2. Colebrook-White friction loss chart for DN16 – DN63 SDR 9 polyethylene pipes, running full of water at 15°C (*k* = 0.015 mm)

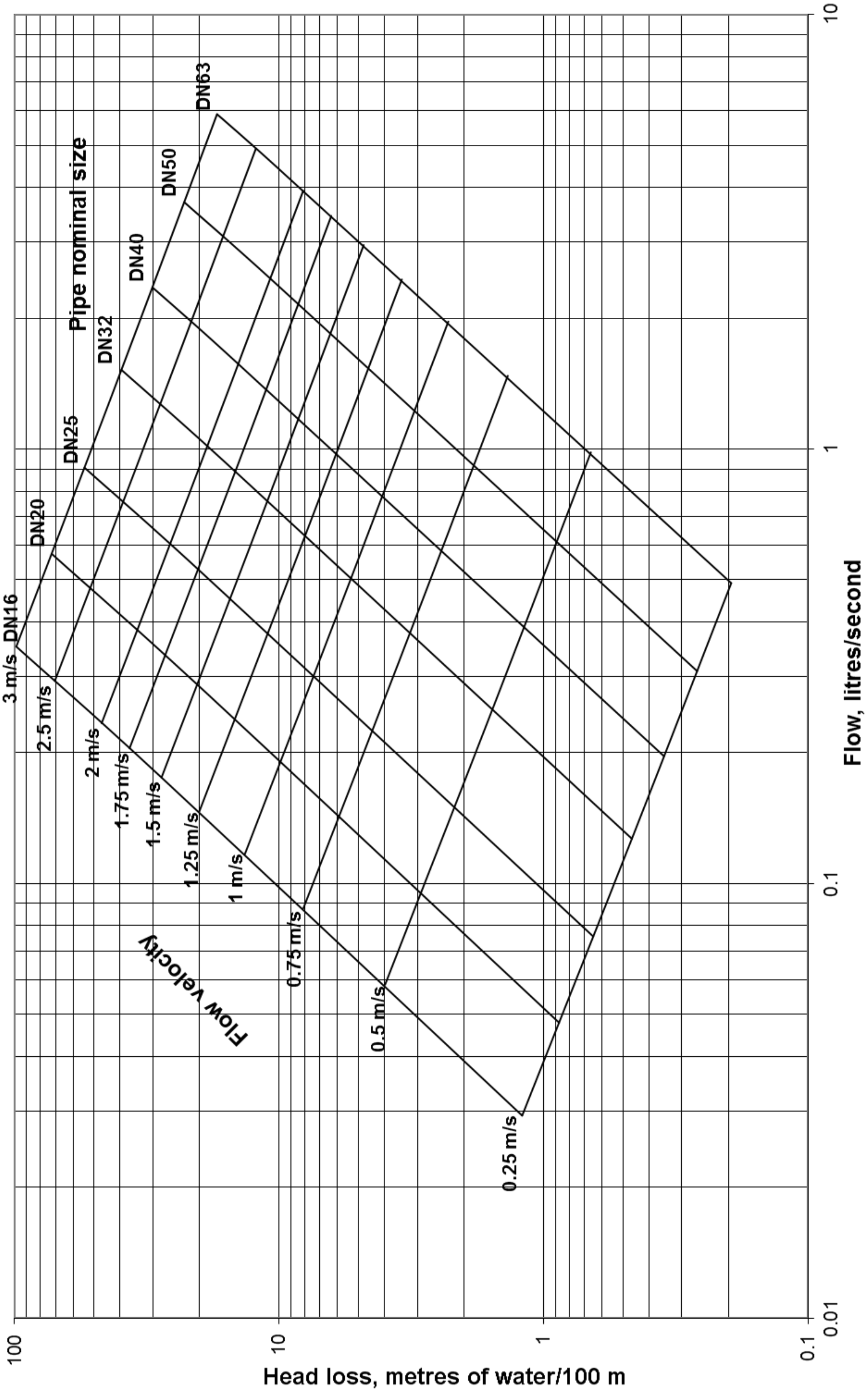


Fig. 3. Colebrook-White friction loss chart for DN16 – DN63 SDR 11 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

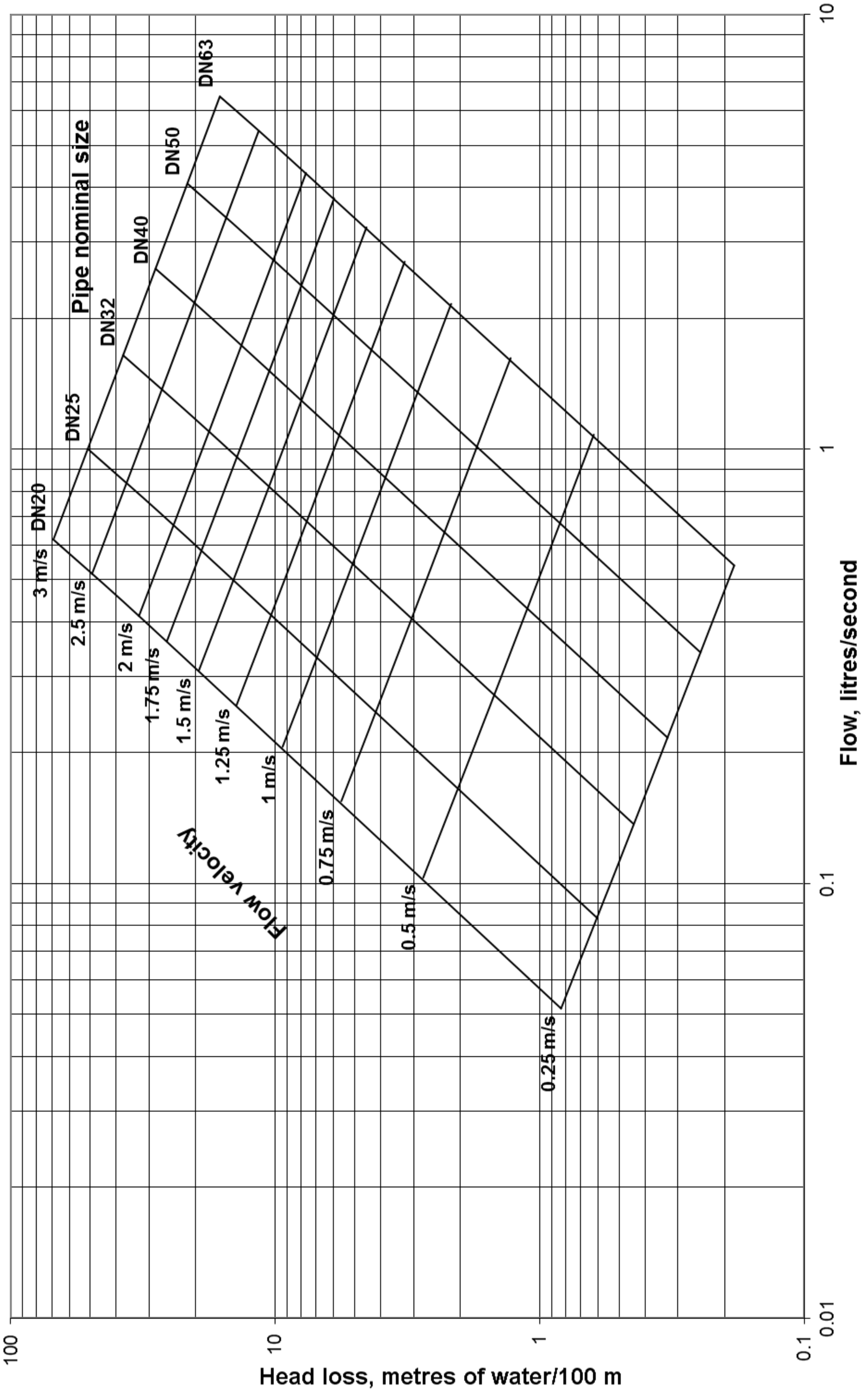


Fig. 4. Colebrook-White friction loss chart for DN20 – DN63 SDR 13.6 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

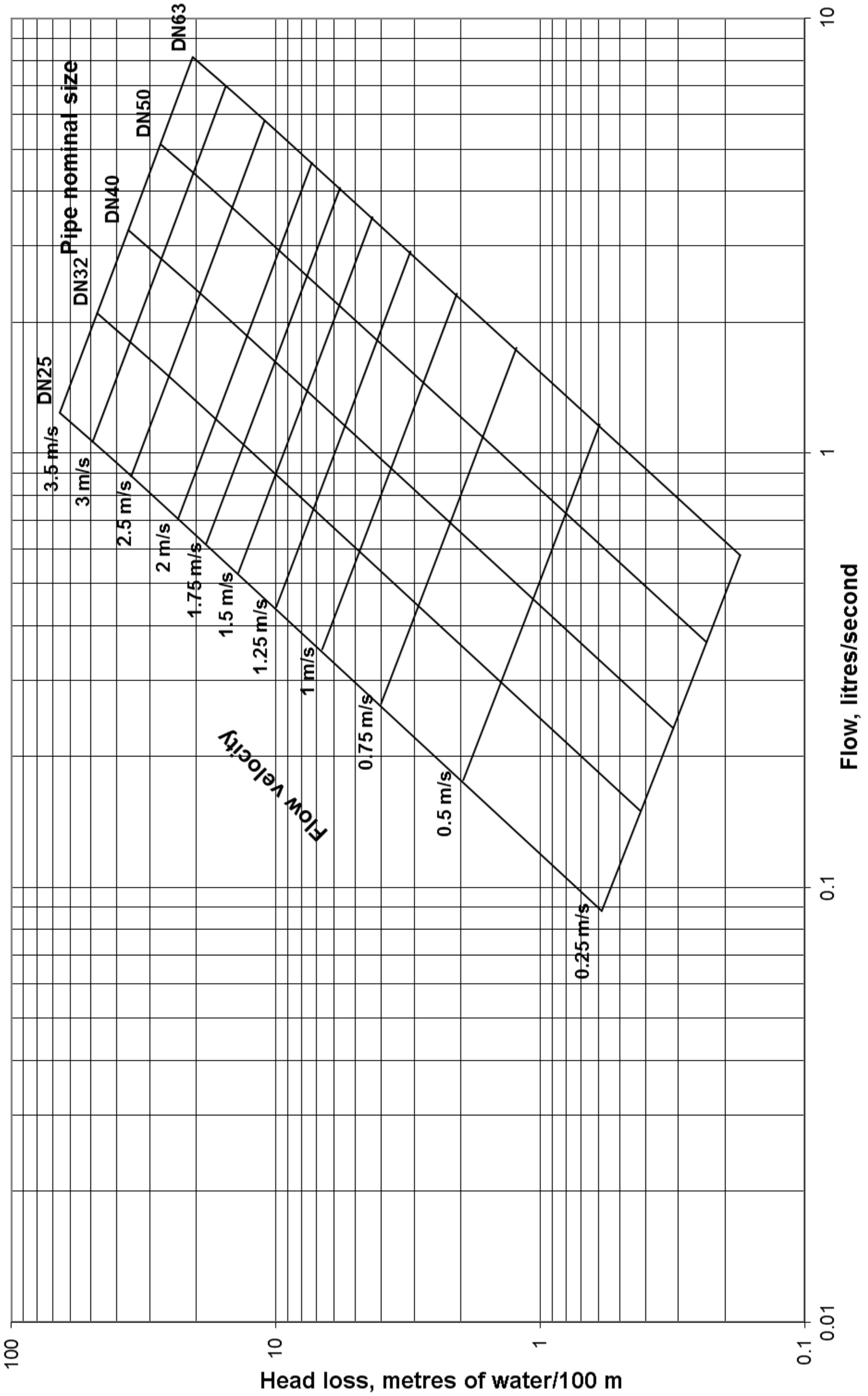


Fig. 5. Colebrook-White friction loss chart for DN25 – DN63 SDR 17 polyethylene pipes, running full of water at 15°C (*k* = 0.015 mm)

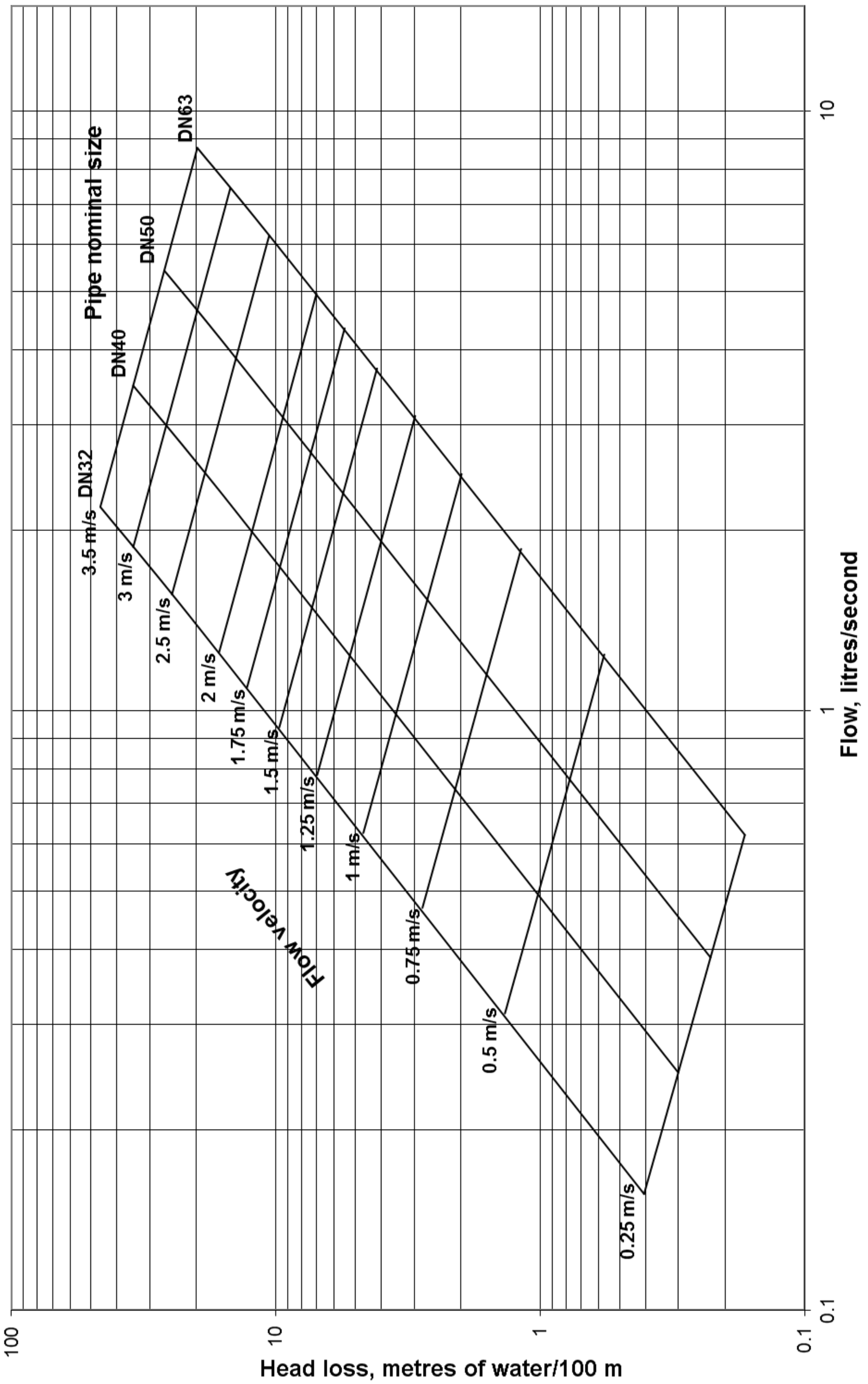


Fig. 6. Colebrook-White friction loss chart for DN32 – DN63 SDR 21 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

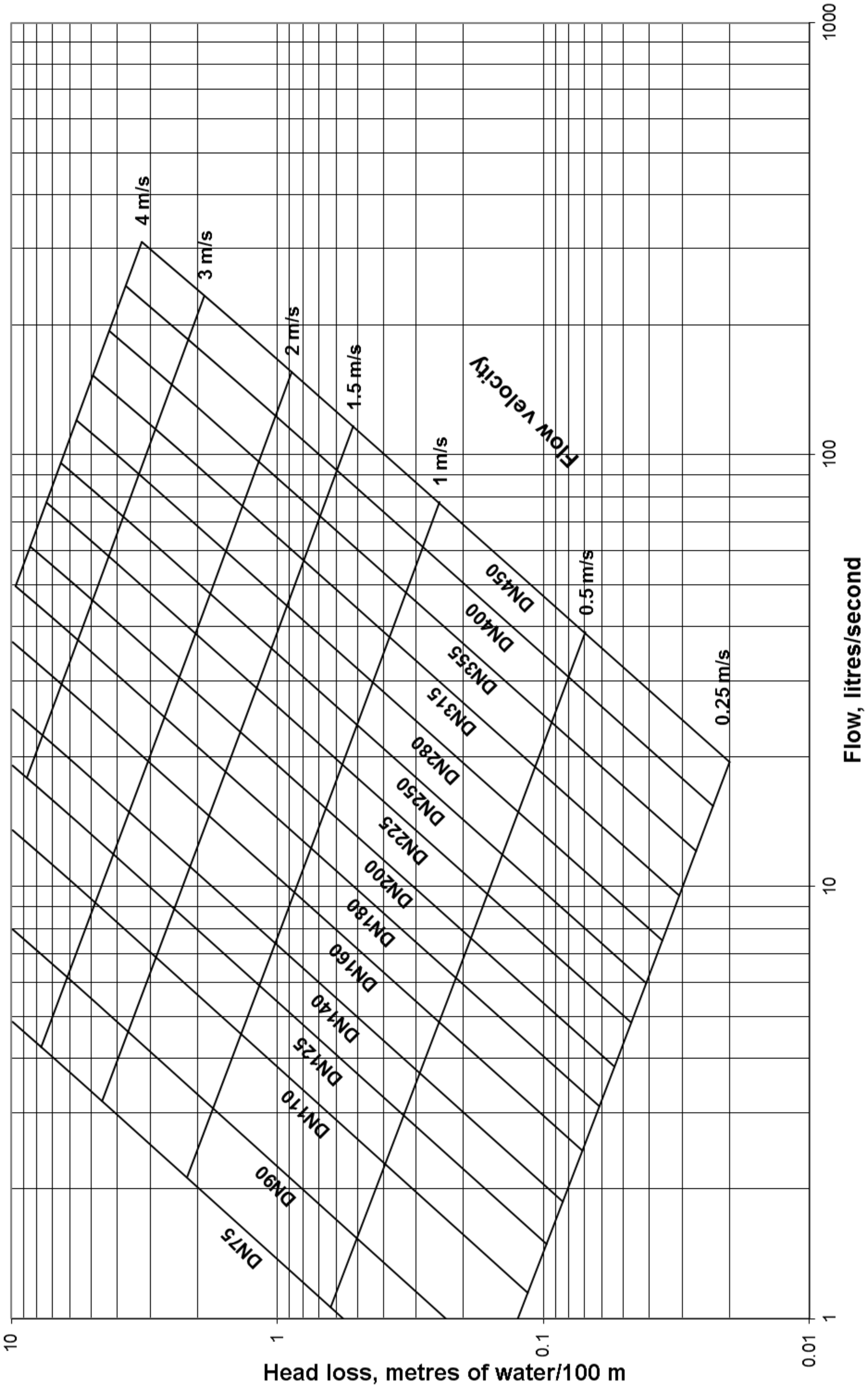


Fig. 7. Colebrook-White friction loss chart for DN75 – DN450 SDR 7.4 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

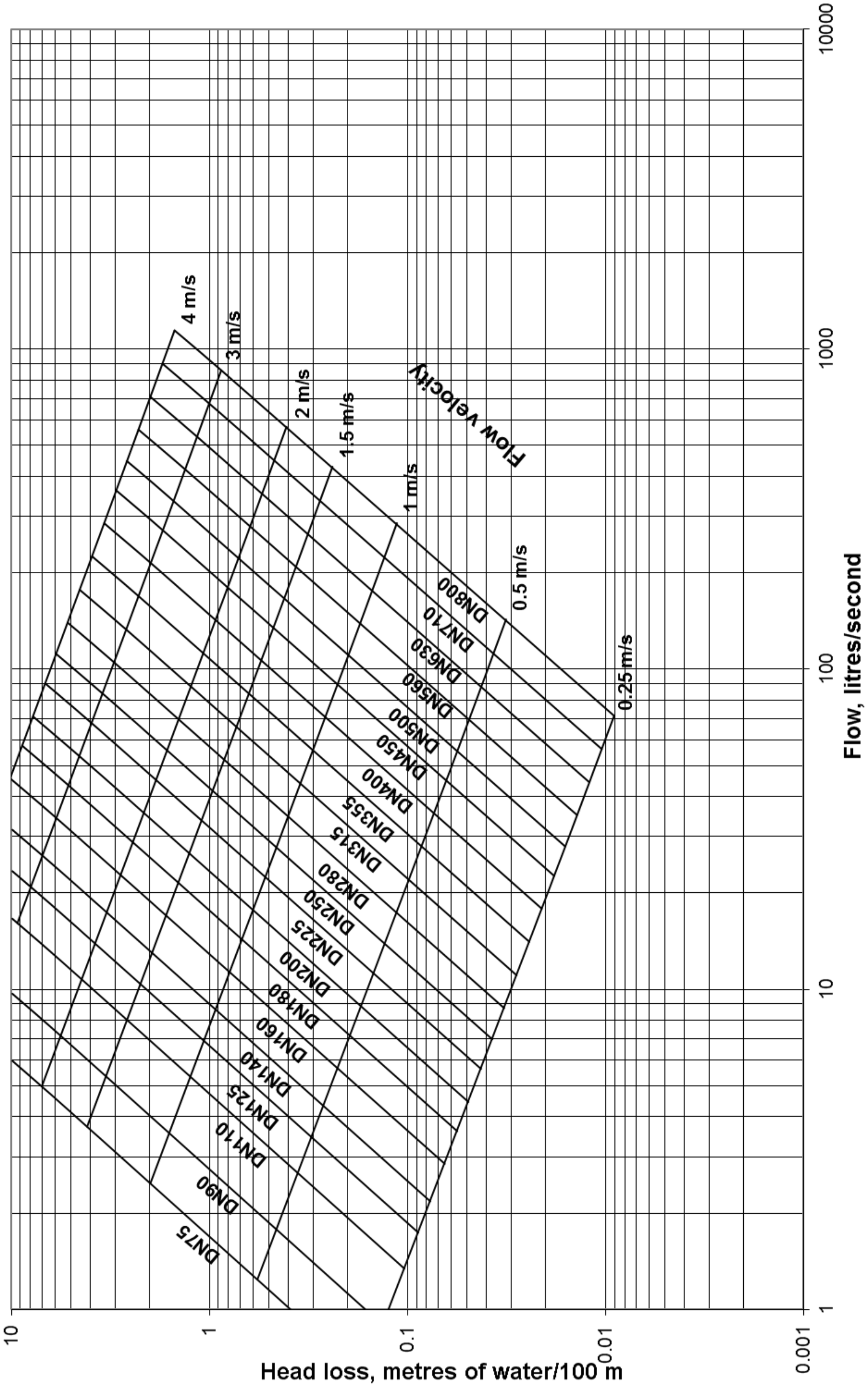


Fig. 8. Colebrook-White friction loss chart for DN75 – DN800 SDR 9 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

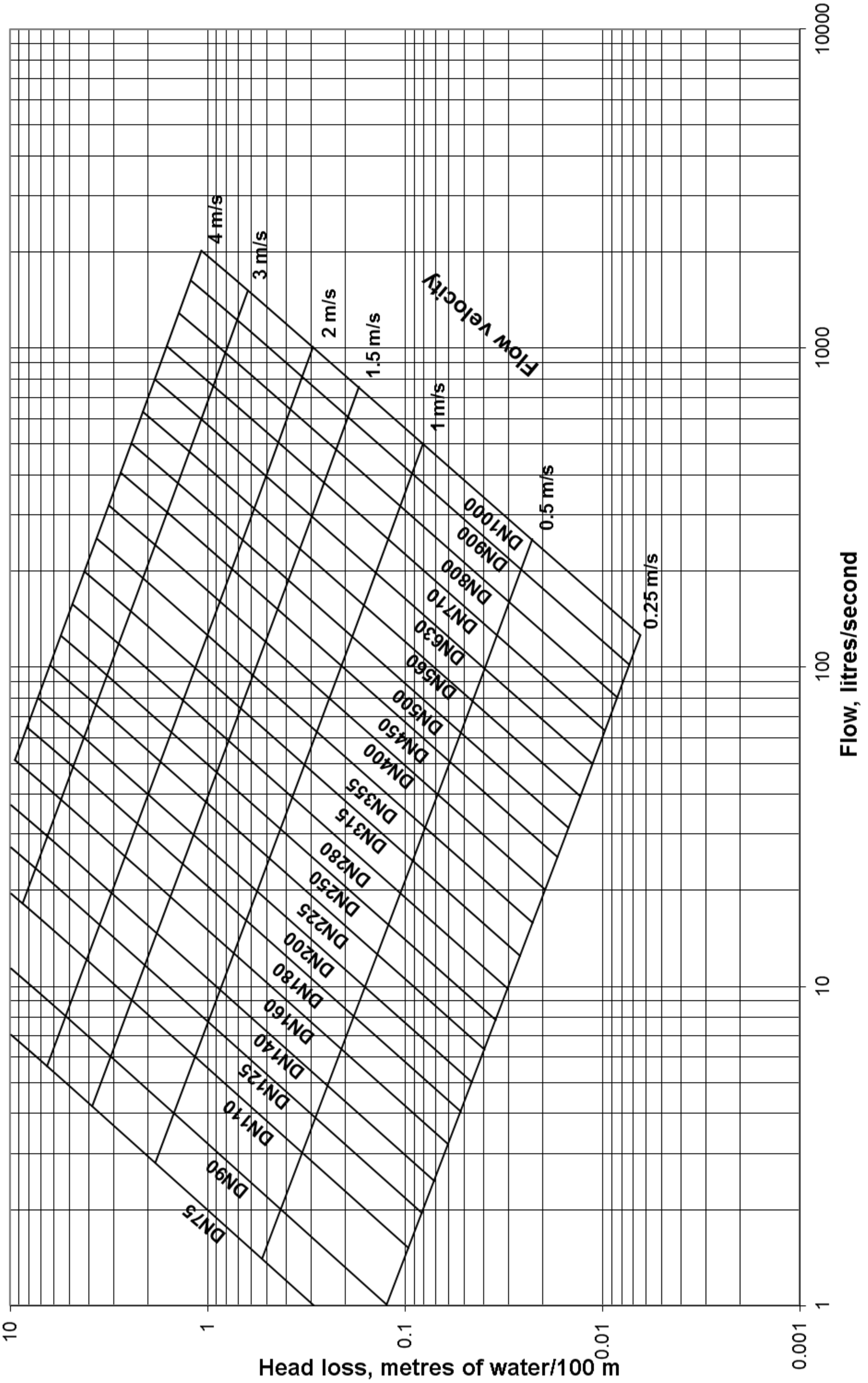


Fig. 9. Colebrook-White friction loss chart for DN75 – DN1000 SDR 11 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

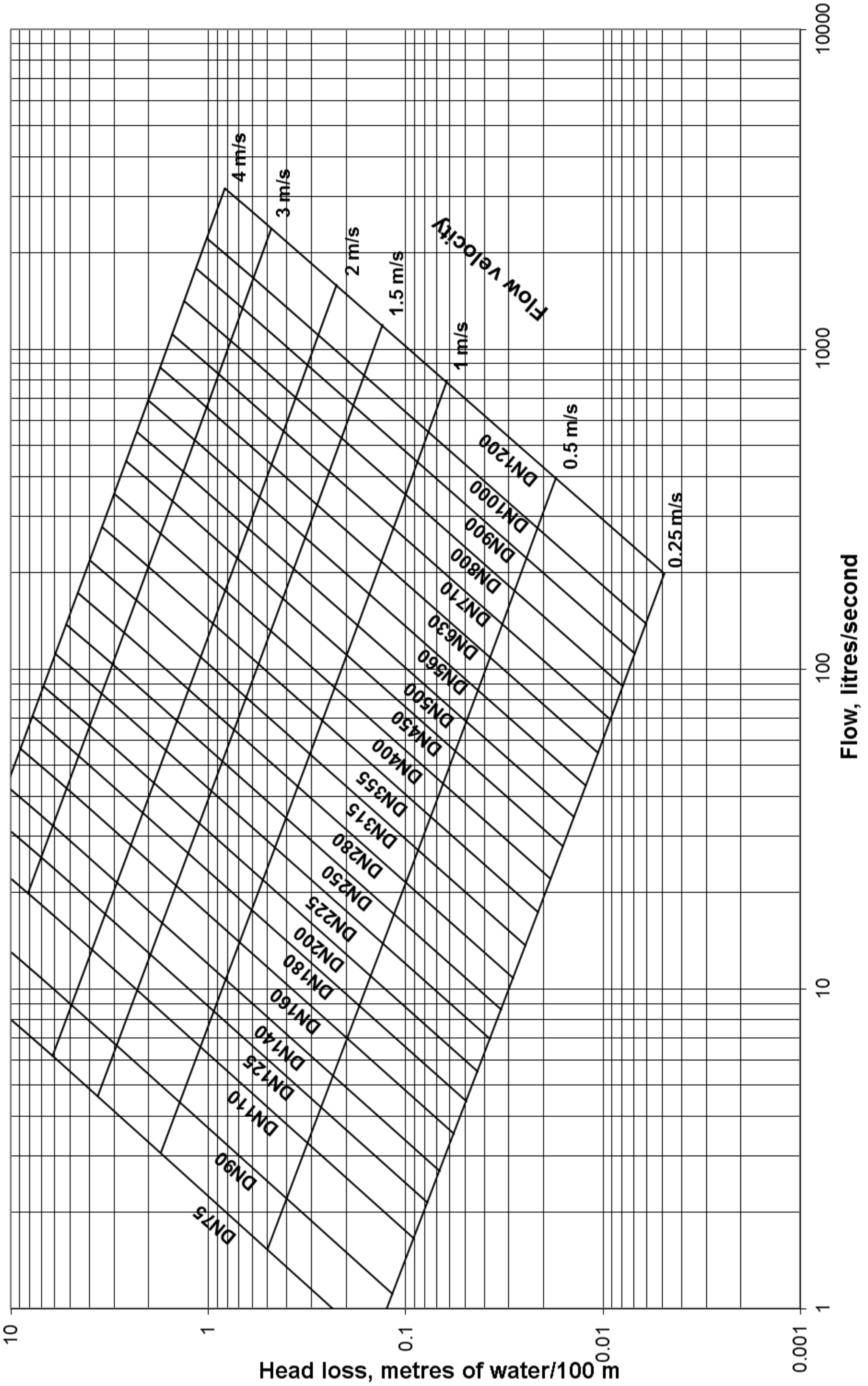


Fig. 10. Colebrook-White friction loss chart for DN75 – DN1200 SDR 13.6 polyethylene pipes, running full of water at 15°C (*k* = 0.015 mm)

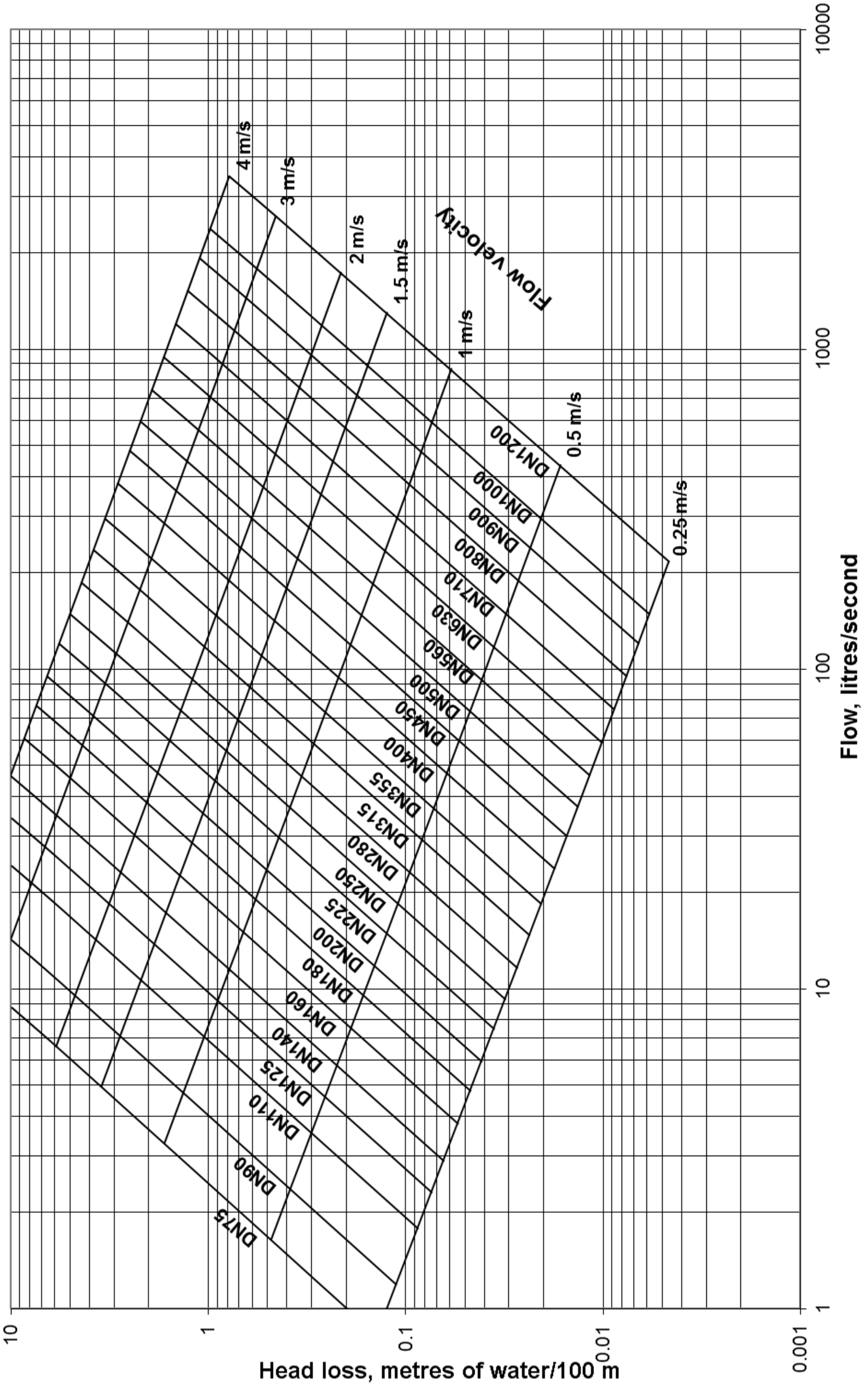


Fig. 11. Colebrook-White friction loss chart for DN75 – DN1200 SDR 17 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

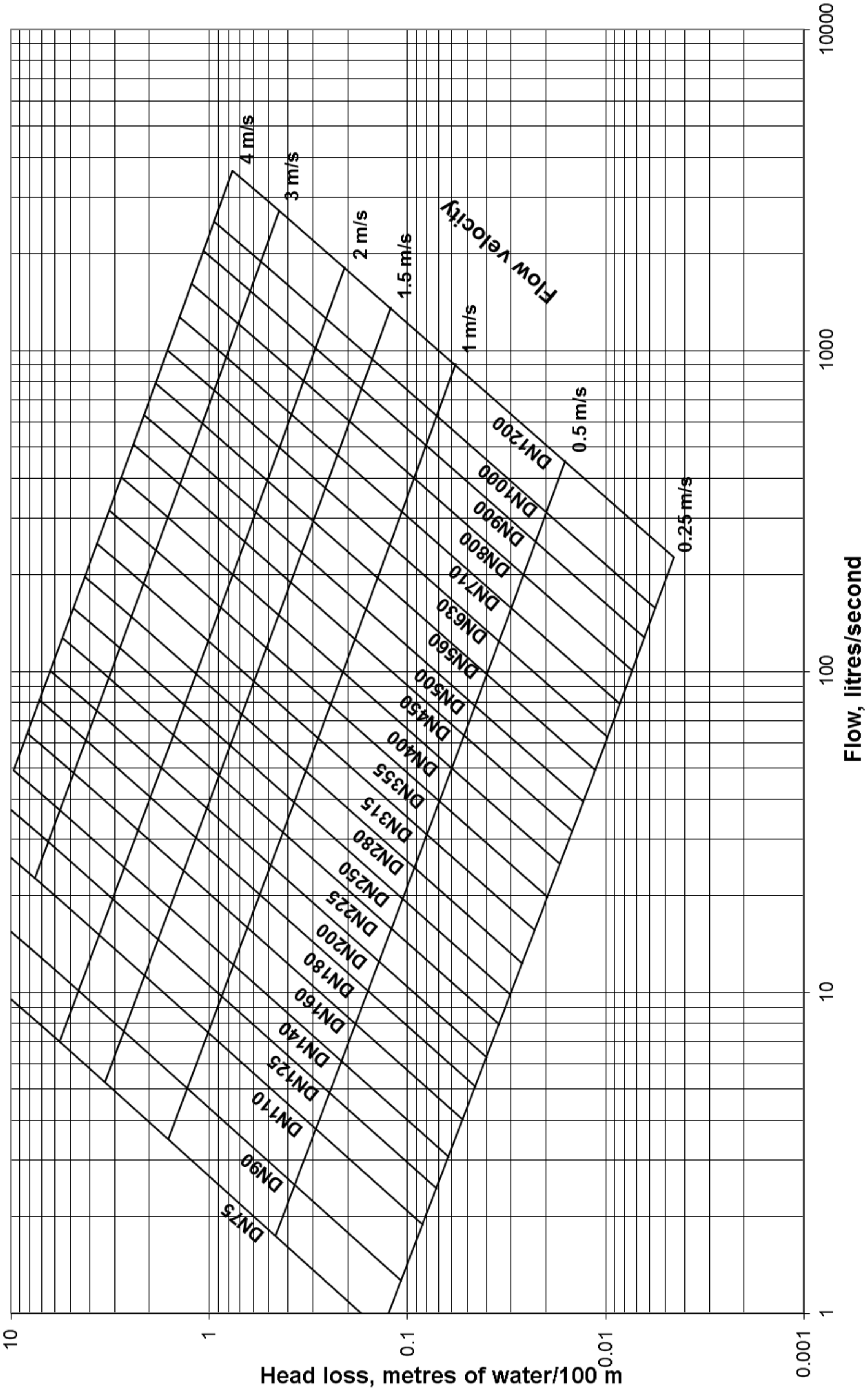


Fig. 12. Colebrook-White friction loss chart for DN75 – DN1200 SDR 21 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

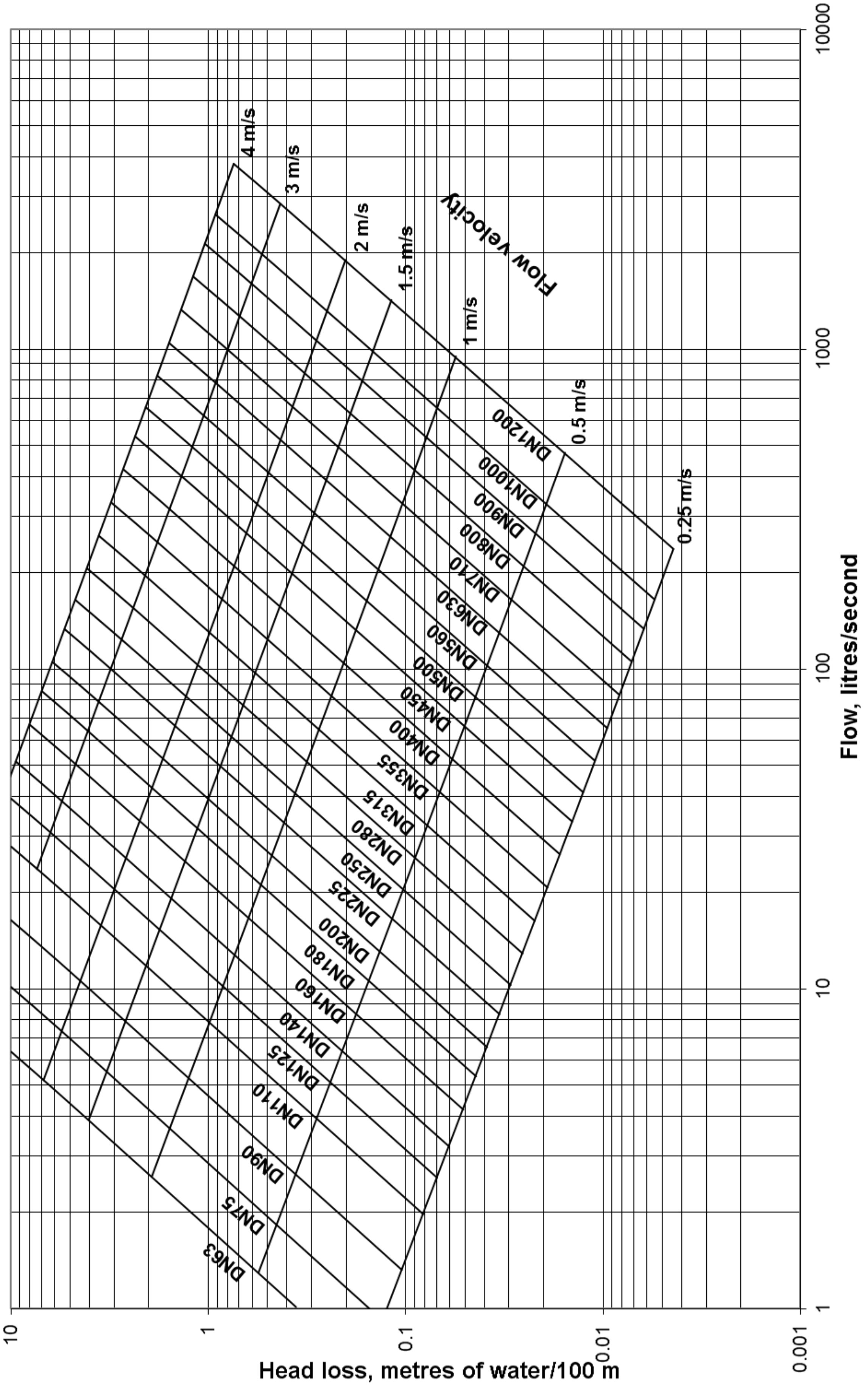


Fig. 13. Colebrook-White friction loss chart for DN63 – DN1200 SDR 26 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

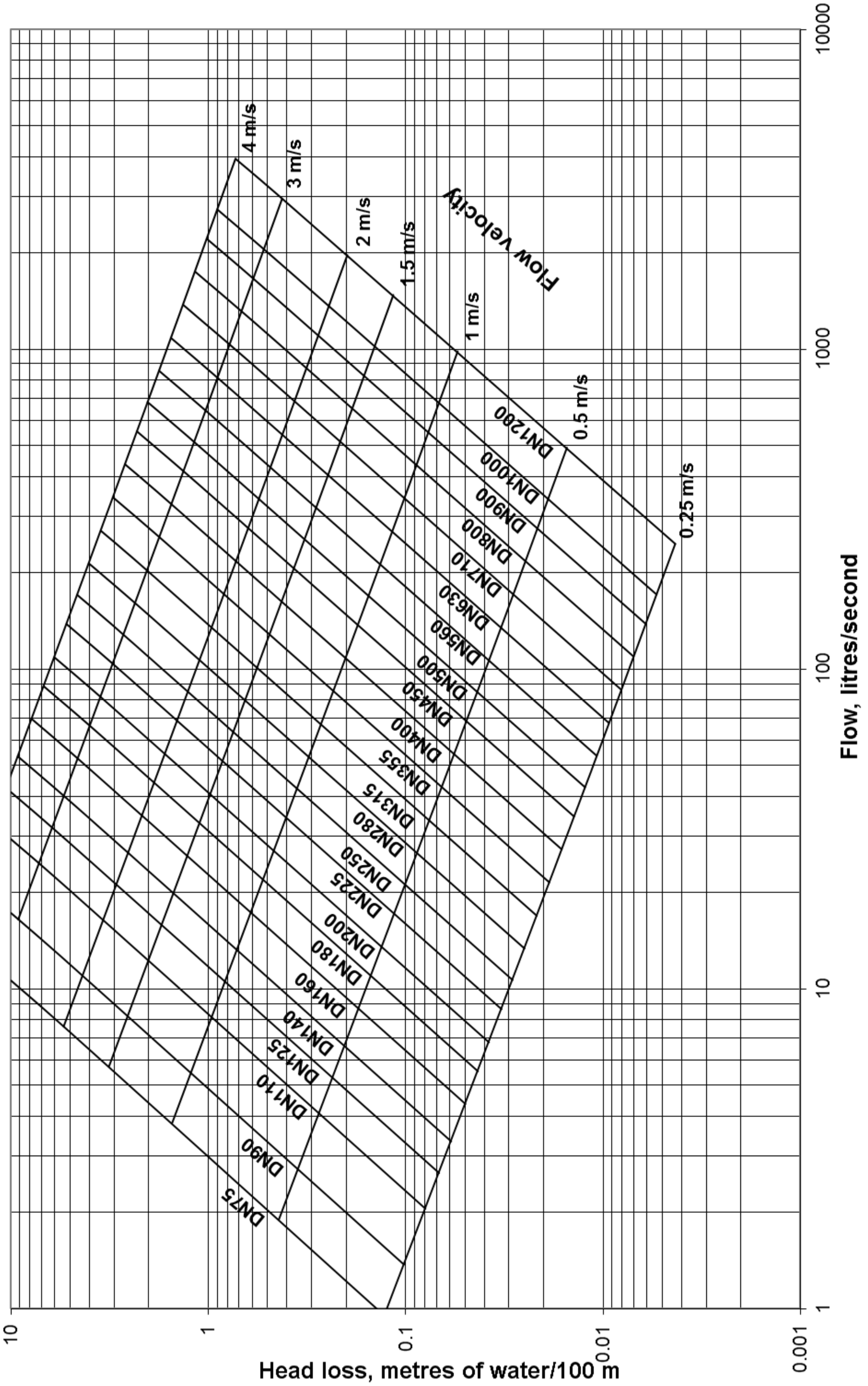


Fig. 14. Colebrook-White friction loss chart for DN75 – DN1200 SDR 33 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

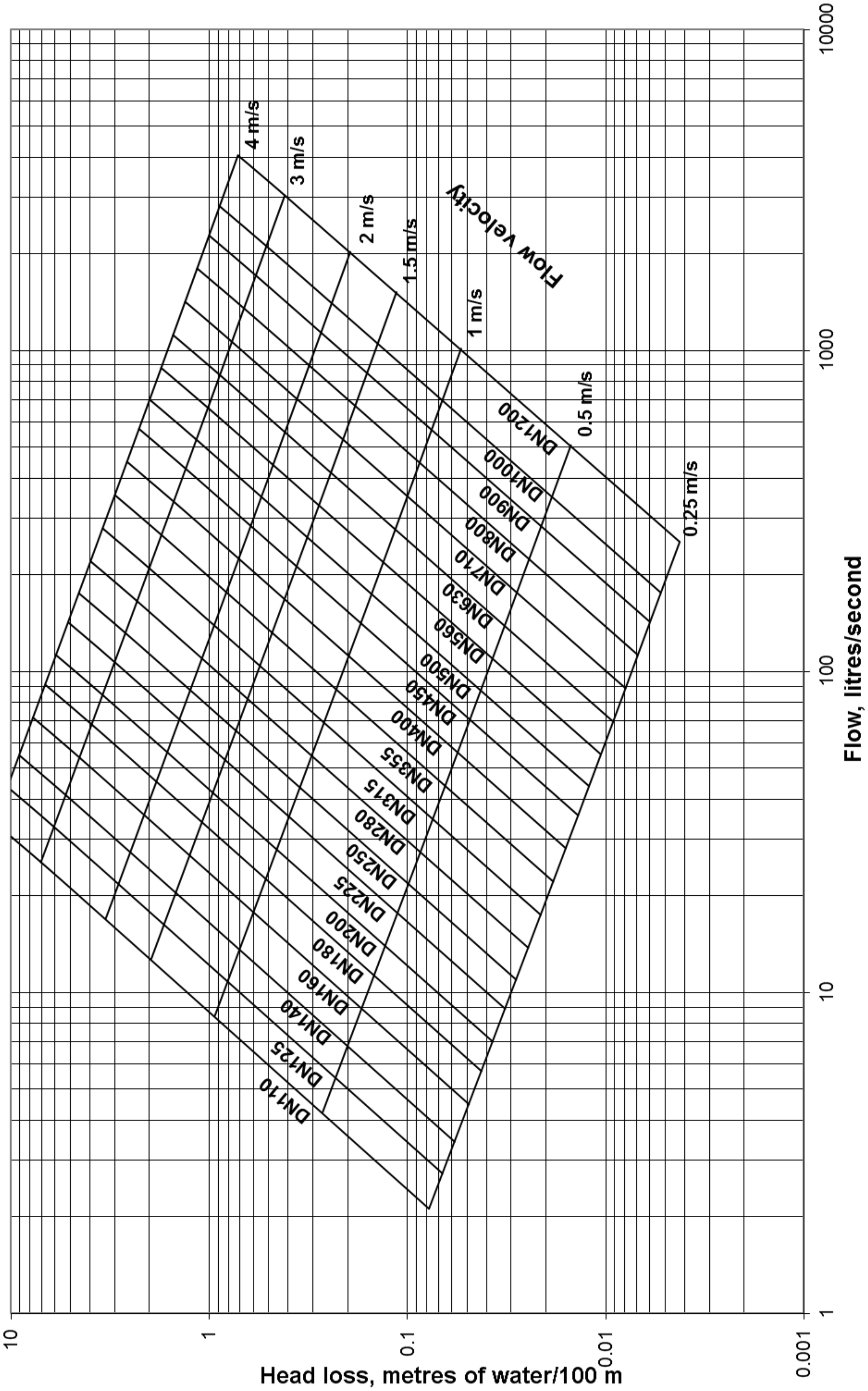


Fig. 15. Colebrook-White friction loss chart for DN110 – DN1200 SDR 41 polyethylene pipes, running full of water at 15°C (k = 0.015 mm)

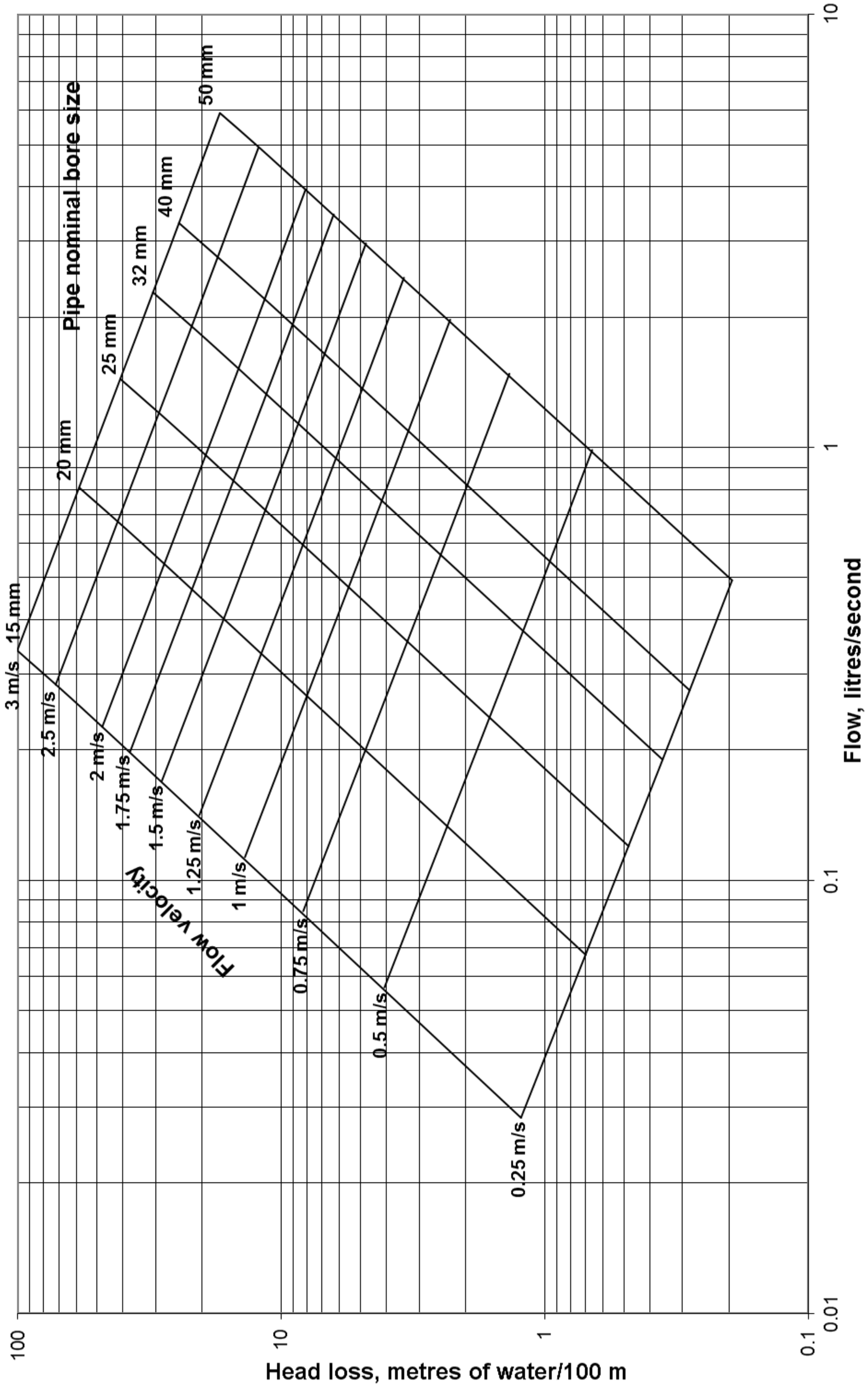
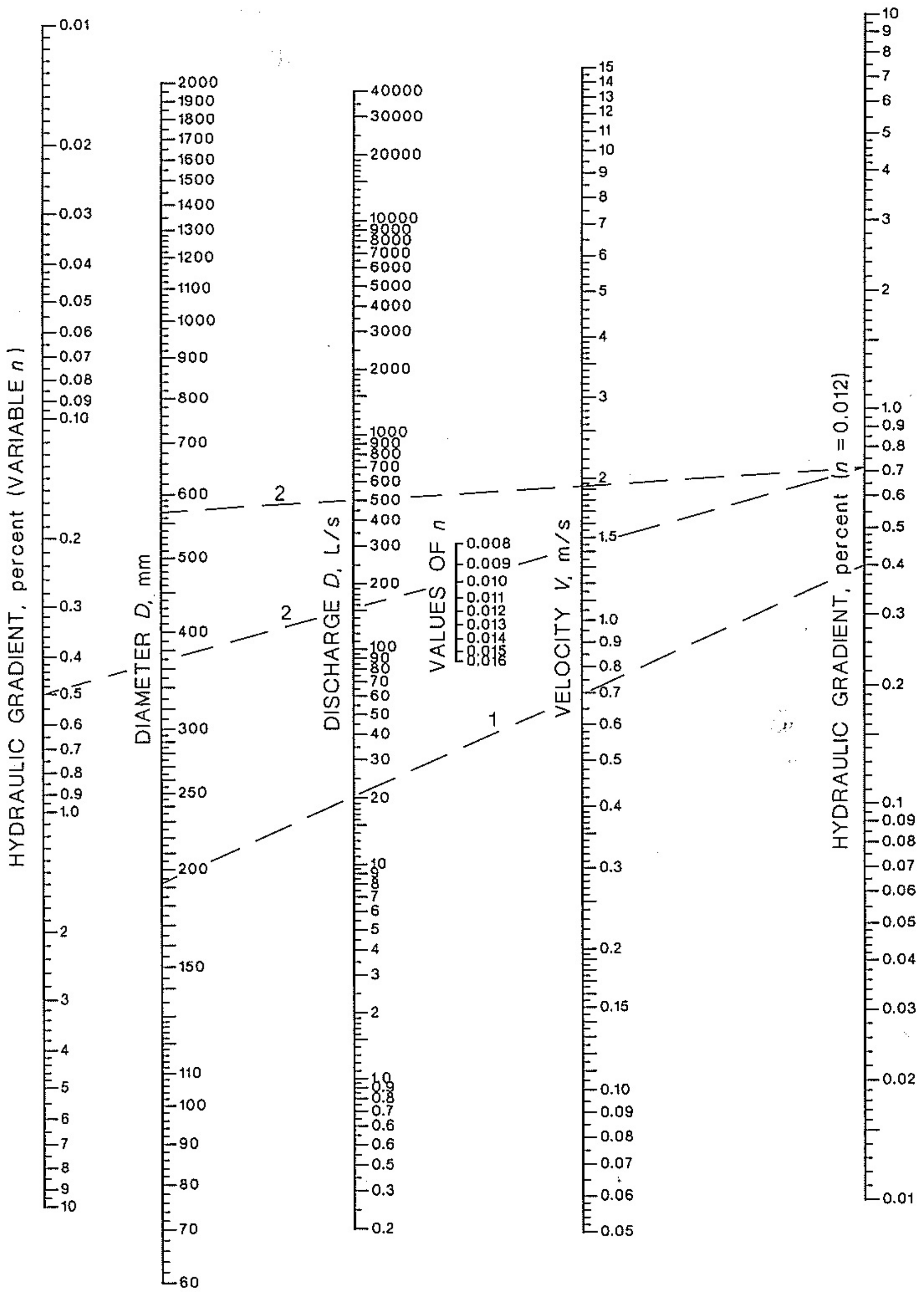


Fig. 16. Colebrook-White friction loss chart for 15mm - 50mm ID W&F LDPE pressure pipes, running full of water at 15°C (*k* = 0.015 mm)



NOTE: $n = 0.012$ use the hydraulic gradient scale at right of chart. For values of n other than 0.012 use the inverted hydraulic gradient scale at left of chart by drawing a straight line from the hydraulic gradient scale for $n = 0.012$ through the appropriate value on the values of n scale (see Example 2).

Examples:

1. Given $n = 0.012$; $Q = 20$ L/s; Hydraulic gradient = 0.4 percent
   Find: $D = 192$ mm; $V = 0.69$ m/s.
2. Given $n = 0.010$; $Q = 500$ L/s; Hydraulic gradient = 0.5 percent
   Find: $D = 572$ mm; $V = 1.93$ m/s.

Fig. 17. Chart 12 of AS 2200; Manning formula; D = 60-2000 mm

Valves and fittings are causing additional friction losses to the flow of fluids in a pipeline. The Darcy-Weisbach formula:

$$H = f \times \frac{L \times V^2}{D \times 2g}, \qquad \text{(HD-16)}$$

modified for head losses in fittings becomes:

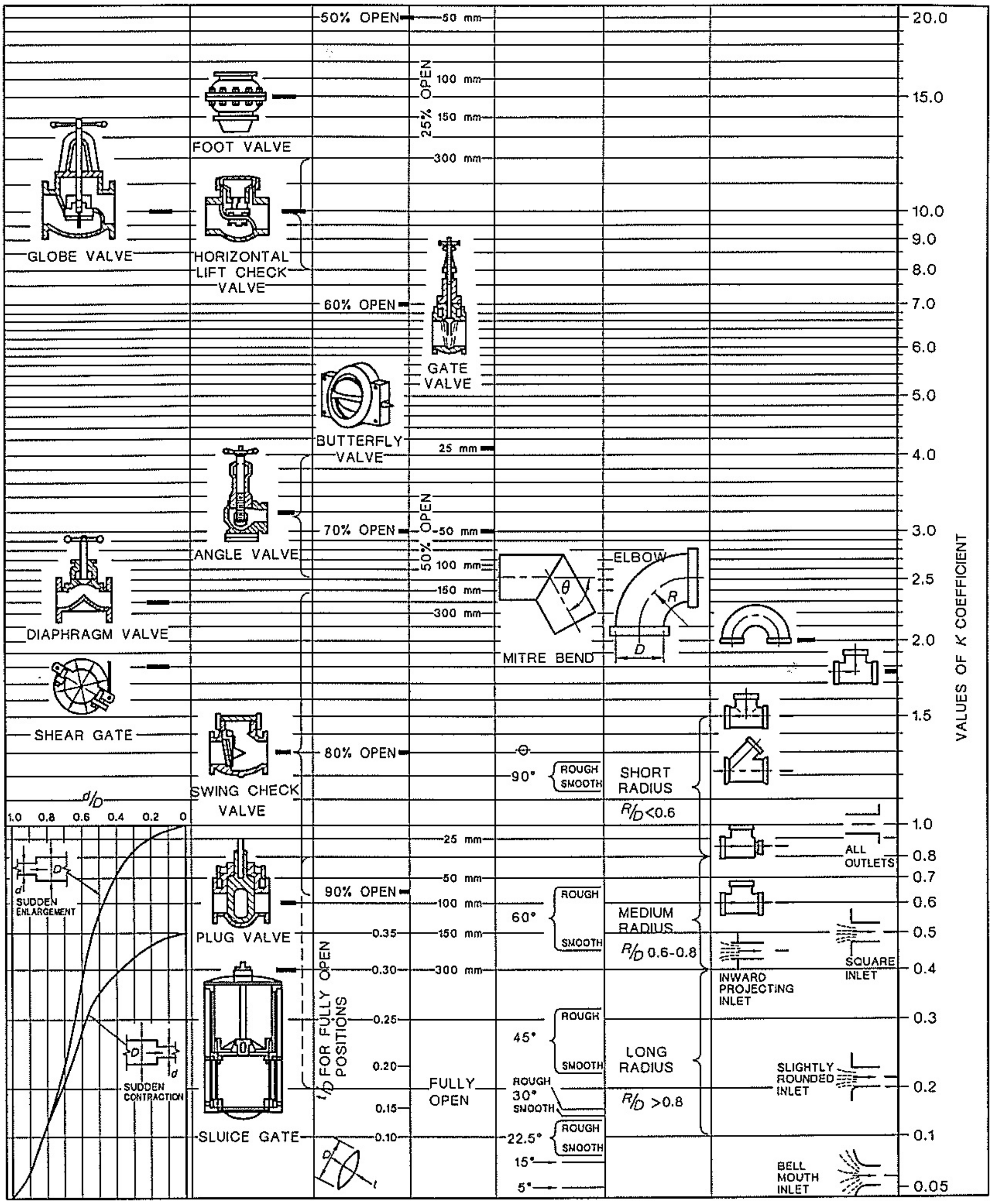
$$H = k \times \frac{V^2}{2g}, \qquad \text{(HD-17)}$$

where
- H – head loss, m,
- L – pipe length, m,
- V – average flow velocity, m/s,
- D – mean inside diameter of pipe, m,
- f – friction factor, dimensionless, dependent upon surface roughness and Reynolds number; see also (HD-6),
- k – friction coefficient, dimensionless, dependent on type of fitting: see Fig. 18 displaying Chart 14 of AS 2200,
- g – gravitational acceleration, m/s².

Comparing formulae (HD-17) and (HD-16) for straight length of pipe, the frictional resistance of valves, fittings, obstructions, etc., may be expressed in terms of equivalent length of straight pipe:

$$L = k \times \frac{D}{f}. \qquad \text{(HD-18)}$$

The effect of the frictional resistance created by the **internal beads** in butt welded joints may be neglected in normal circumstances, but may also be taken into consideration for smaller pipe sizes or where the joints are frequent.



NOTES:

1. To obtain approximate head loss in metres multiply k by $V^2/2g$ (V = velocity in m/s, g = acceleration due to gravity in m/s^2).
2. All valves fully open unless otherwise indicated.
3. Brackets signify a range of values.

Fig. 18. Chart 14 of AS 2200: Resistance coefficients of valves and fittings

Note: For partially closed gate valve, k may be taken as: 1.0 for ¼ closed, 6.0 for ½ closed, 24.0 for ¾ closed.

Pipes filled with liquid may be subjected to a **pressure wave** caused by a sudden significant change in flow velocity. Such events, known as **water hammer**, are usually caused by starting and stopping of pumps, opening and closing of valves, failures of pipeline components, etc. This results in a short-term pressure surge above usual working pressure.

Due to its viscoelastic properties, Waters & Farr polyethylene pipes provide excellent surge tolerance compared to pipes of different materials. For the same flow velocity change of the same liquid, surge pressures in polyethylene pipe are about 80% less than in ductile iron pipe and about 50% less than in PVC pipe.

The pressure change, ΔP, and the wave velocity, C, are approximately correlated by the following:

$$\Delta P = \frac{\rho}{g} \times C \times \Delta V, \qquad \text{(HD-19)}$$

where ΔP – pressure change, N/m² (1 N/m² = 1 × 10^{-6} MPa),
ρ – fluid density, kg/m³; for water, ρ = 1000 kg/m³ may be assumed,
g – gravitational acceleration; g = 9.807 m/s² may be assumed,
C – wave velocity (usually referred to as celerity), m/s,
ΔV – fluid flow velocity change, m/s.

Celerity may be calculated by the following formula:

$$C = \left[\frac{\rho}{g} \times \left(\frac{1}{E_w} + \frac{\text{SDR}}{E_b} \right) \right]^{-1/2} \times 10^3, \qquad \text{(HD-20)}$$

where SDR – Standard Dimension Ratio, dimensionless,
E_w – fluid bulk modulus, MPa; for water, E_w = 2150 MPa may be assumed,
E_b – pipe material modulus of elasticity, short-term, MPa; may be taken, at 20°C: for PE 80B, E_b = 700 MPa, and for PE 100, E_b = 950 MPa.

The pressure change is superimposed on the pipe system, and may be either positive or negative. Conservative estimates show that in general, PE 80B and PE 100 pipes will withstand occasional surge pressures at least equal to their nominal pressure rating (in addition to the nominal working pressure), or at least equal to half of the nominal pressure rating in case of recurrent surges (like frequent repetitive pump start-stop operations), without de-rating of the nominal pressure rating of the pipe. Very high wave velocity, or very high frequency of surge events (causing fatigue in the pipe material), may cause necessity to de-rate the nominal pressure rating of the pipe.

Polyethylene pipes can resist quite low transient negative pressures that may occur during a surge event, without collapse. Where a full (or near full) vacuum generation is possible, buckling resistance of the pipe may be estimated (and consequently, use of pipes of lower SDR may be advisable). Refer to buckling calculations given, for instance, in AS/NZS 2566.1. External dynamic (cyclic) loading imposed on pipe buried under a road is usually not taken into consideration, but may become more significant for very shallow burial or bad quality of the road.

Effect of surges on pipe systems is dependent not only on surge pressure magnitude, pressurisation rate and surge frequency, but also on the system design (including arrangement of restraints and connections, types of fittings used, in-line equipment characteristics, etc.). High resistance of pipes themselves to surge events does not mean that other components of the pipeline are not affected by dynamic loading caused by surges. Surge wave analysis is complex, and if required, should be undertaken by experts with extensive knowledge and experience. In simplified version, the analysis may be carried out using available computer programs.

Water hammer effects may be controlled by reducing the suddenness of a velocity change. Where possible, repetitive operations causing surge waves should be properly controlled, e.g. the flow must not be shut off any faster than it takes the surge wave initiated at the beginning of valve closure to travel the length of the pipeline and return (note, that effective closure time for a valve is usually taken as one half of the actual closing time). This wave travel time may be calculated as follows:

$$t = \frac{2L}{C}, \qquad \text{(HD-21)}$$

where t – time, s,
L – length of the affected pipeline, m,

C – wave velocity, m/s.

Reduction or even elimination of water hammer effects can be achieved by installation of appropriate equipment, like pressure/vacuum relief valves, speed controls for valve closure and opening, surge arrestors, surge tanks, as well as by careful design of the pipe system, by proper procedure of initial filling of the pipeline, etc.

More detailed information on polyethylene pipe and fitting design for dynamic stresses is given in PIPA Australia Guidelines POP010A and POP010B (http://www.pipa.com.au/technical/pop-guidelines).

In a case of partially filled pipe flow (Fig. 19), proportional (in relation to full pipe flow) average velocity as calculated by Manning formula (HD-7), proportional discharge as well as proportional hydraulic radius and utilised area at various filling levels (expressed as a ratio of height and inside diameter), is given as a chart on Fig. 20.

Flow of water in partially filled pipes may also be calculated using Colebrook-White formula (HD-2), where mean internal diameter, D, is replaced by a value (4R), R being hydraulic radius, m (formula HD-22):

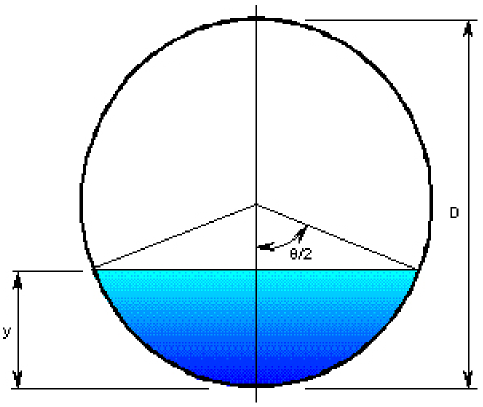


Fig. 19. Partially filled pipe

$$V = -2 \times \sqrt{2g \times 4R \times J} \times \log\left\{\frac{k}{3.7D} + \frac{2.51\nu}{D \times \sqrt{2g \times 4R \times J}}\right\}. \quad \text{(HD-22)}$$

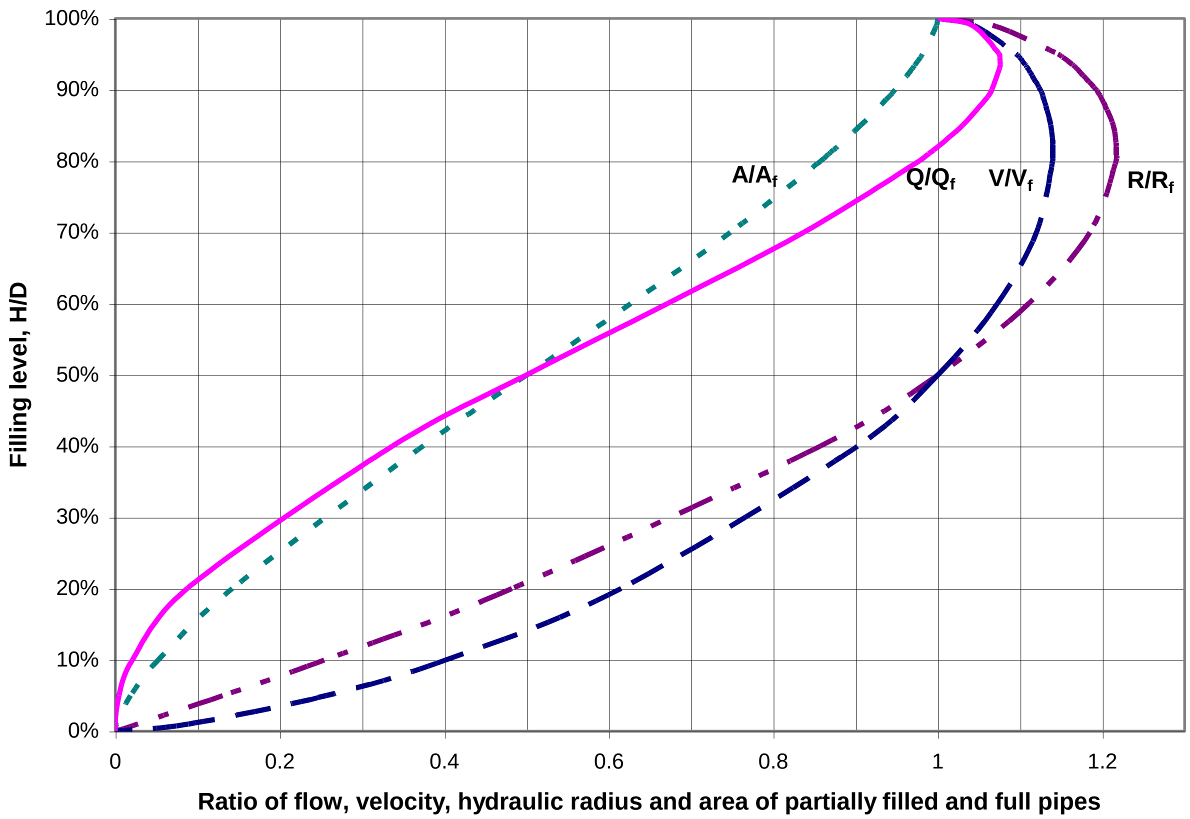


Fig. 20. Proportional flow in partially filled pipes