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Systems & Solutions

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Pipe Selection

Vinidex PE pipes are available in a comprehensive range of sizes up to 1000mm diameter, and pressure classes in accordance with the requirements of AS/NZS 4130 - Polyethylene (PE) pipes for pressure applications.

Additional sizes and pressure classes to AS/NZS 4130 requirements are added from time to time and subject to minimum quantity requirements, pipes made to specific sizes, lengths or pressure classes are available.

The Standard AS/NZS 4130 includes a range of PE material designations based on the Minimum Required Stress (MRS), and classified as PE63, PE80, and PE100. When pipes are made to the same dimensions, but from different rated PE materials, then the pipes will have different pressure ratings.

The relationship between the dimensions of the pipes, the PE material classification and the working pressure rating are as shown in Table 4.1.

For simplicity, the dimensions of the pipe have been referred in terms of the Standard Dimension Ratio (SDR) where:

$$SDR = \frac{\text{Outside Diameter}}{\text{Wall Thickness}}$$

Table 4.1 Comparison of SDR & Pressure Ratings (PN)

SDR	41	33	26	21	17	13.6	11	9	7.4
PE80	PN3.2	PN4	-	PN6.3	PN8	PN10	PN12.5	PN16	PN20
PE100	PN4	-	PN6.3	PN8	PN10	PN12.5	PN16	PN20	PN25

Notes:

PE Long term rupture stress at 20°C (MPa x 10) to which a minimum design factor is applied to obtain the 20°C hydrostatic design hoop stress.

PN Pipe pressure rating at 20°C (MPa x10).

SDR Nominal ratio of outside diameter to wall thickness.

Pipe Dimensions

Table 4.2 PE Pipe Dimensions AS/NZS 4130

Polyethylene Pipe Dimensions (based on AS/NZS 4130-1997, Polyethylene pipes for pressure applications.)

Nominal Size DN	SDR 41		SDR 33		SDR 26		SDR 21		SDR 17		SDR 13.6		SDR 11		SDR 9		SDR 7.4	
	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)	Min. Wall Thickness (mm)	Mean I.D. (mm)
16	1.6	13	1.6	13	1.6	13	1.6	13	1.6	13	1.6	13	1.6	13	1.8	12	2.2	11
20	1.6	17	1.6	17	1.6	17	1.6	17	1.6	17	1.6	17	1.9	16	2.3	15	2.8	14
25	1.6	22	1.6	22	1.6	22	1.6	22	1.6	22	1.9	21	2.3	20	2.8	19	3.5	18
32	1.6	29	1.6	29	1.6	29	1.6	29	1.9	28	2.4	27	2.9	26	3.6	24	4.4	23
40	1.6	37	1.6	37	1.6	37	1.9	36	2.4	35	3.0	34	3.7	32	4.5	31	5.5	28
50	1.6	47	1.6	47	2.0	46	2.4	45	3.0	44	3.7	42	4.6	40	5.6	38	6.9	35
63	1.6	60	2.0	59	2.4	58	3.0	57	3.8	55	4.7	53	5.8	51	7.1	48	8.6	45
75	1.9	71	2.3	70	2.9	69	3.6	67	4.5	66	5.5	63	6.8	61	8.4	58	10.3	53
90	2.2	86	2.8	84	3.5	83	4.3	81	5.4	78	6.6	76	8.2	73	10.1	69	12.3	65
110	2.7	105	3.4	103	4.3	101	5.3	99	6.6	96	8.1	93	10.0	89	12.3	84	15.1	78
125	3.1	119	3.9	117	4.8	115	6.0	113	7.4	110	9.2	106	11.4	101	14.0	96	17.1	89
140	3.5	133	4.3	131	5.4	129	6.7	126	8.3	123	10.3	118	12.7	114	15.7	108	19.2	99
160	4.0	152	4.9	150	6.2	148	7.7	144	9.5	140	11.8	136	14.6	130	17.9	123	21.9	114
180	4.4	171	5.5	169	6.9	166	8.6	163	10.7	158	13.3	153	16.4	145	20.1	138	24.6	128
200	4.9	190	6.2	188	7.7	184	9.6	180	11.9	175	14.7	170	18.2	162	22.4	154	27.3	143
225	5.5	215	6.9	211	8.6	207	10.8	203	13.4	198	16.6	191	20.5	183	25.1	173	30.8	161
250	6.2	238	7.7	235	9.6	230	11.9	225	14.8	219	18.4	212	22.7	203	27.9	192	34.2	179
280	6.9	267	8.6	263	10.7	258	13.4	253	16.6	246	20.6	238	25.4	228	31.3	215	38.3	200
315	7.7	300	9.7	296	12.1	290	15.0	285	18.7	278	23.2	268	28.6	256	35.2	242	43.0	226
355	8.7	338	10.9	333	13.6	328	16.9	320	21.1	311	26.1	301	32.2	289	39.6	273	48.5	255
400	9.8	380	12.3	376	15.3	370	19.1	362	23.7	351	29.4	340	36.3	326	44.7	307	54.6	287
450	11.0	429	13.8	422	17.2	415	21.5	406	26.7	395	33.1	382	40.9	366	50.2	347	61.5	322
500	12.3	476	15.3	470	19.1	462	23.9	452	29.6	440	36.8	424	45.4	407	55.8	384	-	-
560	13.7	534	17.2	526	21.4	518	26.7	506	33.2	494	41.2	475	50.8	455	-	-	-	-
630	15.4	600	19.3	592	24.1	582	30.0	570	37.3	554	46.3	535	57.2	512	-	-	-	-
710	17.4	676	21.8	667	27.2	656	33.9	641	42.1	624	52.2	603	-	-	-	-	-	-
800	19.6	762	24.5	752	30.6	739	38.1	723	47.4	704	58.8	679	-	-	-	-	-	-
900	22.0	858	27.6	846	34.4	831	42.9	814	53.5	791	-	-	-	-	-	-	-	-
1000	24.5	953	30.6	940	38.2	924	47.7	904	59.3	880	-	-	-	-	-	-	-	-

SDR – Nominal ratio of outside diameter to wall thickness. **ID – internal diameter**

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Allowable Operating Pressure

Hydrostatic Design Basis

Vinidex pipes manufactured to AS/NZS 4130, Series 1 have wall thickness and pressure ratings determined by the Barlow formula as follows:

$$T = \frac{PD}{2S + P}$$

T = minimum wall thickness (mm)
P = normal working pressure of pipe (MPa)
D = minimum mean OD (mm)
S = hydrostatic design stress at 20°C (MPa)
See Table 4.2.

Hydrostatic Design Stress

The design of AS/NZS 4130 pipes has been based on the static working pressure operating continuously at the maximum value for the entire lifetime of the pipeline.

The value of maximum hoop stress used in the selection of the pipe wall thickness is known as the Hydrostatic Design Stress (S). This value is dependent upon the type of PE material being used and the pipe material service temperature. In AS/NZS 4131, materials are classified for long term strength by the designation Minimum Required Strength (MRS).

The MRS is the value resulting from extrapolation of short and long term tests to a 50 year point at 20°C.

Note: See Figure 2.1 for typical stress regression curves.

Table 4.3 Hydrostatic Design Stress and Minimum Required Strength – Values

Material Designation	Minimum Required Strength (MRS) MPa	Hydrostatic Design Stress (S) MPa
PE63	5.0	6.3
PE80	6.3	8.0
PE100	8.0	10.0

The Hydrostatic Design Stress (S) is obtained by application of a Design or Safety Factor (F) to the MRS.

See Table 4.3.

$$S = \frac{MRS}{F}$$

The specific value selected for the Design Factor depends on a number of variables, including the nature of the transmitted fluid, the location of the pipeline, and the risk of third party damage.

The wall thickness values for Series 1 pipes to AS/NZS 4130 were derived using a value of 1.25 for F, this being the minimum value applicable.

AS/NZS 4131 specifics MRS values of 6.3 MPa, 8.0 MPa and 10.0 MPa for the grades designated as PE63, PE80 and PE100 respectively.

The relationship between the S and MRS standard values in AS/NZS 4131 is as shown in Table 4.3.

These standard values are polymer dependent and long term properties for each pipe grade material are established by long term testing to the requirements of ISO/DIS 9080 by the polymer producers. Individual PE grades may exhibit different characteristics and PE materials can be provided with enhanced specific properties. In these cases the advice of Vinidex engineers should be obtained.

Maximum Allowable Operating Pressure

$$MAOP = \frac{PN \times 0.125}{F}$$

where

MAOP is the maximum allowable operating pressure in MPa.

PN is the pipe classification in accordance with AS/NZS 4130.

F is the Design Factor.

For example, if the minimum value of F is chosen (F = 1.25), a PN10 pipe will have a MAOP of 1.0 MPa at 20°C.

Where installation applications are used to carry fluids other than water, then another value of the Design Factor may need to be selected. The value selected will depend on both the nature of the fluid being carried and the location of the pipeline installation. For specific installations, the advice of Vinidex engineers should be obtained.

In the case of gas pipes in AS/NZS 4130, both Series 2 and Series 3, a Design Factor ranging between F = 2.0 and F = 4.0 applies depending on the specific installation conditions; see Table 4.6.

Table 4.4 Typical Design Factors

Pipeline Application 20°C	Design Factor F
Water Supply	1.25
Natural Gas	2.0
Compressed Air	2.0
LPG	2.2

Where the Design Factor is varied, then the MAOP for the particular Series 1 pipe PN rating can be calculated as follows:

$$MAOP = \frac{PN \times 0.125}{F}$$

In the particular case of gas distribution, then the type of gas, and the pipeline installation conditions need to be considered. In this case the Design Factor is a combination of a number of sub factors (f_x) which must be factored together to give the final value for F such that:

$$F = f_0 \times f_1 \times f_2 \times f_3 \times f_4 \times f_5$$

Table 4.5 PE Pipe Pressure Ratings

PN Rating Number	Nominal Working Pressure	
	MPa	Head Metres
PN 3.2	0.32	32
PN 4	0.40	40
PN 6.3	0.63	63
PN 8	0.80	80
PN 10	1.00	100
PN 12.5	1.25	125
PN 16	1.60	160
PN 20	2.00	200
PN 25	2.50	250

Table 4.6 Design Factors – Gas Pipes

Installation	Conditions	Design Factor	Value
Fluid type	Natural Gas	f0	2.0
	LPG		2.2
Pipe Form	Straight length	f1	1.0
	Coils		1.2
Soil Temperature (Av. °C)	-10 < t < 0	f2	1.2
	0 < t < 20		1.0
	20 < t < 30		1.1
	30 < t < 35		1.3
Designation	Distribution	f3	1.0
	Transport		0.9
Rapid Crack Resistance		f4	1.0
Population density & area loading			
	Open field	f5	0.9
	Less trafficed roads in inbuilt areas		1.05
	Heavy trafficed roads in inbuilt areas		1.15
	Roads in populated area		1.20
	Roads in industrial area		1.25
	Private area habitation		1.05
	Private area industry		1.20

Note: Where factor values are not listed, consult with Vinidex engineers for recommendations.

Temperature Influences

The physical properties of Vinidex PE pipes are related to a standard reference temperature of 20°C. Where physical property values are quoted to ISO and DIN Standard test methods, these are for the 20°C condition, unless otherwise quoted. Wherever PE pipelines operate at elevated temperatures, the pressure ratings (PN) must be revised.

The temperature to be considered for the re rating is the pipe material service temperature, and the actual operating conditions for each specific installation must be evaluated.

For long length installations a temperature gradient will exist along the length of the pipe line. This gradient will be dependent upon site conditions, and the fluid being carried will approach the ambient temperature of the surrounds.

The rate of temperature loss will be determined by inlet temperature, fluid flow rate, soil conductivity, ambient temperature and depth of burial. As these factors are specific to each installation, the temperature gradient calculations are complex and in order to assist the designer, Vinidex have developed computer software to predict the temperature gradient along the pipeline.

This is available on request to Vinidex design engineers.

The grades of PE specified in AS/NZS 4131 are produced by different polymerisation methods, and as such have different responses to temperature variations.

Pipe Classification (PN) is based on continuous operation at 20°C and the pressure rating will be reduced for higher temperatures. In addition, as PE is an oxidising material, the lifetime of some grades will be limited by elevated temperature operation. Table 4.7 gives temperature rerating data for Vinidex pipes made to AS/NZS 4130.

In these tables, allowable working pressures are derived from ISO 13761* and assume continuous operation at the temperatures listed.

Extrapolation limit is maximum allowable extrapolation time in years, based on data analysis in accordance with ISO/DIS 9080**, and at least two years of test at 80°C for PE80B and PE100. Actual product life may well be in excess of these values.

The performance of compounds used in the manufacture of Vinidex pipes to AS/NZS 4130 has been verified by appropriate data analysis.

In addition, Vinidex offers pipes made from specialised compounds for particular applications, such as elevated temperature use.

Contact Vinidex engineers for special requirements.

Note:

* Plastics pipes and fittings – pressure reduction factors for polyethylene pipeline systems for use at temperatures above 20°C.

** Plastics piping and ducting systems – determination of long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation.

Service Lifetimes

The design basis used in AS/NZS 4130 for PN rating of PE pipes to determine the minimum wall thickness for each diameter and PN rating provides for the steady and continuous application of the maximum allowable working pressure over an arbitrary period of 50 years.

The selection of the long term hydrostatic design stress value (**HDS**) is dependent on the specific grade of PE and the pipe material service temperature. For the grades of PE materials contained in AS/NZS 4131 the specific values are contained in Table 4.3.

As these values are polymer dependent, individual grades may exhibit different characteristics and materials can be provided with enhanced properties for crack resistance or elevated temperature performance. In these cases the advice of Vinidex design engineers should be obtained.

Vinidex PE pipes are continually tested in combinations of elevated temperature (80°C water conditions) and pressure to ensure compliance with specification requirements.

The adoption of a 50 year design life in AS/NZS 4130 to establish a value of the **HDS** is arbitrary, and does not relate to the actual service lifetime of the pipeline.

Where pipelines are used for applications such as water supply, where economic evaluations such as present value calculations are performed, the lifetimes of PE lines designed and operated within the AS guidelines may be regarded as 70–100 years for the purpose of the calculations. Any lifetime values beyond these figures are meaningless, as the assumptions made in other parts of the economic evaluations outweigh the effect of pipe lifetime.

Pipe Design for Variable Operational Conditions

The following examples assist in the design and selection of polyethylene pipes for variable operating conditions

Given Operating Conditions

Pressure/Temperature/Time Relationship

Determine

Material

Class of pipe

Life

Steps

1. Assume a material

2. Determine Class from Temperature Rating Table 4.7

Note: For brief periods at elevated temperature it may be appropriate to decrease the safety factor to a value of x, i.e. multiply the working pressure by:

$$\frac{1.25}{x}$$

3. By the following process, assess whether life is 'used up'

For each combination of time and temperature, estimate the proportion of life 'used up' by using the time/ temperature relationships in the table.

If the proportion is less than unity, the material is satisfactory.

Example

Pumped system normally working at a maximum head, including surge of 60m. At startup, the mean pipe wall temperature is 55°C, dropping to 35°C after 1 hour. Pump operation is for 10 hours per day, with a system life of 15 years.

1. Assume PE 80B

2. Determine Pipe Class

The worst situation is operation at 55°C.

From Table 4.7, PN10 pipe at 55°C has an allowable working head of 60m.

PN10 pipe is therefore satisfactory.

3. Determine Life

Total time at 55°C

= 1 x 365 x 15 = 5475h = 0.625y.

From Table 4.7, L_{min} for 55°C is 24 years, therefore proportion of time used is:

$$\frac{0.625}{24} = 0.026 = 2.6\%$$

Total time at 35°C

= 9 x 365 x 15 = 49275h = 5.625y.

From the table, L_{min} for 35°C is 100 years, therefore proportion of time used is:

$$\frac{5.625}{100} = 0.056 = 5.6\%$$

Total proportion is 8.2% of life used in 15 years (6.25 years actual operation).

The data in the tables are obtained from the use of ISO 13761 and ISO/DIS 9080, and are appropriate for compounds typically used by Vinidex.

Table 4.7 Temperature Rating Tables

PE80B

	Extrapolation	Permissible System Operating Head (m)							
Temp °C	Limit Years	PN 3.2	PN 4	PN 6.3	PN 8	PN 10	PN 12.5	PN 16	PN20
20	200	32	40	63	80	100	125	160	200
25	100	30	38	59	75	94	117	150	188
30	100	28	35	55	70	88	109	140	175
35	100	26	32	50	64	80	100	128	160
40	100	24	30	47	60	75	94	120	150
45	60	22	28	44	56	70	88	112	140
50	36	21	26	41	52	65	81	104	130
55	24	19	24	38	48	60	75	96	120
60	12	18	23	35	45	56	70	90	113
65	8	17	21	33	42	53	66	84	105
70	5	16	20	31	39	49	61	78	98
75	2	14	18	28	36	45	56	72	90
80	2	13	17	26	33	41	52	66	83

PE80C

	Extrapolation	Permissible System Operating Head (m)							
Temp °C	Limit Years	PN 3.2	PN 4	PN 6.3	PN 8	PN 10	PN 12.5	PN 16	PN20
20	50	32	40	63	80	100	125	160	200
25	50	29	36	57	72	90	113	144	180
30	30	26	33	51	65	81	102	130	163
35	18	23	29	46	58	73	91	116	145
40	12	20	25	39	50	63	78	100	125
45	6	18	23	35	45	56	70	90	113

PE100

	Extrapolation	Permissible System Operating Head (m)								
Temp °C	Limit Years	PN 3.2	PN 4	PN 6.3	PN 8	PN 10	PN 12.5	PN 16	PN20	PN25
20	200	32	40	63	80	100	125	160	200	250
25	100	30	38	59	75	94	117	150	188	233
30	100	28	35	55	70	88	109	140	175	218
35	100	26	32	50	64	80	100	128	160	200
40	100	24	30	47	60	75	94	120	150	185
45	60	22	28	44	56	70	88	112	140	175
50	36	21	26	41	52	65	81	104	130	163
55	24	19	24	38	48	60	75	96	120	150
60	12	18	23	35	45	56	70	90	113	140
65	8	17	21	33	42	53	66	84	105	130
70	5	16	20	31	39	49	61	78	98	120
75	2	14	18	28	36	45	56	72	90	113
80	2	13	17	26	33	41	52	66	83	105

E Modulus

The E modulus of polyethylene varies with temperature, duration of loading, stress, and the particular grade of material.

However, in order to facilitate engineering calculations, it is generally appropriate to group materials into categories and adopt 'typical' values of E.

Table 4.8 lists E values in MPa for PE80B (MDPE), PE80C (HDPE), and PE100 (HDPE).

Selection of Wall Thickness for Special Applications

For a required nominal diameter (DN) and working pressure, the necessary wall thickness for special applications may be calculated using the Barlow formula:

$$t = \frac{P.DN}{2.S + P}$$

where

t = minimum wall thickness (mm)

P = maximum working pressure (MPa)

DN = nominal outside diameter (mm)

S = design hoop stress (MPa)

$$S = \frac{MRS}{F}$$

where

F = design factor, typically 1.25 for water

Table 4.8 E Values (MPa)

PE 80B

Temp °C	3 min	1h	5h	24h	1y	20y	50y
0	1050	830	740	650	410	320	300
20	700	550	490	430	270	215	200
40	530	410	370	320	200	160	150
60	400	300	280	250	160	-	-

PE 80C

Temp °C	3 min	1h	5h	24h	1y	20y	50y
0	1080	850	740	660	400	320	300
20	750	590	520	460	280	220	205
40	470	370	320	290	180	140	130
60	210	170	150	130	80	-	-

PE 100

Temp °C	3 min	1h	5h	24h	1y	20y	50y
0	1380	1080	950	830	520	410	380
20	950	750	660	580	360	280	260
40	700	550	490	430	270	210	190
60	530	420	370	320	200	-	-

Example

P = 900kPa = 0.9MPa

DN = 630

MRS = 10 (PE100)

F = 1.25

$$S = \frac{10}{1.25} = 8.0\text{MPa}$$

$$t = \frac{0.9 \times 630}{16 + 0.9} = 33.6\text{mm}$$

Hydraulic Design

Design Basis

Vinidex Polyethylene (PE) pipes offer advantages to the designer due to the smooth internal bores which are maintained over the working lifetime of the pipelines. The surface energy characteristics of PE inhibit the build up of deposits on the internal pipe surfaces thereby retaining the maximum bore dimensions and flow capacities.

The flow charts presented in this section relate the combinations of pipe diameters, flow velocities and head loss with discharge of water in PE pipelines. These charts have been developed for the flow of water through the pipes. Where fluids other than water are being considered, the charts may not be applicable due to the flow properties of these different fluids. In these cases the advice of Vinidex engineers should be obtained.

There are a number of flow formulae in common use which have either a theoretical or empirical background. However, only the Hazen-Williams and Colebrook-White formulae are considered in this section.

Hazen - Williams

The original Hazen-Williams formula was published in 1920 in the form:

$$v = C_1\, r^{0.63}\, s^{0.54}\, 0.001^{-0.04}$$

where

C_1 = Hazen-Williams roughness coefficient

r = hydraulic radius (ft)

s = hydraulic gradient

The variations inherent with diameter changes are accounted for by the introduction of the coefficient C_2 so that

$$C_2 = C_1\, r^{0.02}$$

Adoption of a Hazen-Williams roughness coefficient of 155 results in the following relationship for discharge in Vinidex PE pipes

$$Q = 4.03 \times 10^{-5}\, D^{2.65}\, H^{0.54}$$

where

Q = discharge (litres/second)

D = internal diameter (mm)

H = head loss (metres/100 metres length of pipe)

Flow charts for pipe systems using the Hazen - Williams formula have been in operation in Australia for over 30 years. The charts calculate the volumes of water transmitted through pipelines of various materials, and have been proven in practical installations.

Colebrook - White

The development from first principles of the Darcy-Weisbach formula results in the expression

$$H = \frac{fLv^2}{D\,2g}$$

where

$$f = \frac{64}{R}$$

and

f = Darcy friction factor

H = head loss due to friction (m)

D = pipe internal diameter (m)

L = pipe length (metres)

v = flow velocity (m/s)

g = gravitational acceleration (9.81 m/s²)

R = Reynolds Number

This is valid for the laminar flow region (R 2000), however, as most pipe applications are likely to operate in the transition zone between smooth and full turbulence, the transition function developed by Colebrook-White is necessary to establish the relationship between f and R.

$$\frac{1}{f^{1/2}} = -2\log_{10}\left(\frac{k}{3.7D} + \frac{2.51}{Rf^{1/2}}\right)$$

where

k = Colebrook-White roughness coefficient (m)

The appropriate value for PE pipes is:

k = 0.007×10^{-3} m

= 0.007 mm

This value provides for the range of pipe diameters, and water flow velocities encountered in normal pipeline installations.

Flow Variations

The flow charts presented for PE pipes are based on a number of assumptions, and variations to these standard conditions may require evaluation as to the effect on discharge.

Water Temperature

The charts are based on a water temperature of 20°C. A water temperature increase above this value, results in a decrease in viscosity of the water, with a corresponding increase in discharge (or reduced head loss) through the pipeline.

An allowance of approximately 1% increase in the water discharge must be made for each 3°C increase in temperature above 20°C. Similarly, a decrease of approximately 1% in discharge occurs for each 3°C step below 20°C water temperature.

Pipe Dimensions

The flow charts presented in this section are based on mean pipe dimensions of Series 1 pipes made to AS/NZS 4130 PE pipes for Pressure applications.

Surface Roughness

The roughness coefficients adopted for Vinidex PE pipes result from experimental programs performed in Europe and the USA, and follow the recommendations laid down in Australian Standard AS2200 - Design Charts for Water Supply and Sewerage.

Head Loss in Fittings

Wherever a change to pipe cross section, or a change in the direction of flow occurs in a pipeline, energy is lost and this must be accounted for in the hydraulic design.

Under normal circumstances involving long pipelines these head losses are small in relation to the head losses due to pipe wall friction.

However, geometry and inlet/exit condition head losses may be significant in short pipe runs or in complex installations where a large number of fittings are included in the design.

The general relationship for head losses in fittings may be expressed as:

$$H = K\left(\frac{V^2}{2g}\right)$$

where

H = head loss (m)

V = velocity of flow (m/s)

K = head loss coefficient

g = gravitational acceleration (9.81 m/s²)

The value of the head loss coefficient K is dependent on the particular geometry of each fitting, and values for specific cases are listed in Table 4.9.

The total head loss in the pipeline network is then obtained by adding together the calculations performed for each fitting in the system, the head loss in the pipes, and any other design head losses.

Worked Example

What is the head loss occurring in a 250mm equal tee with the flow in the main pipeline at a flow velocity of 2 m/s?

$$H = K\left(\frac{V^2}{2g}\right)$$

where

K = 0.35 (Table 4.9)

V = 2 m/s

g = 9.81 m/s

$$H = \frac{0.35 \times 2^2}{2 \times 9.81}$$

If the total system contains 15 tees under the same conditions, then the total head loss in the fittings is 15 x 0.07 = 1.05 metres.

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Flow Chart Worked Examples

Example 1 - Gravity Main (refer Figure 4.1)

A flow of water of 32 litres/second is required to flow from a storage tank located on a hill 50 metres above an outlet. The tank is located 4.5 km away from the outlet.

Hence the information available is :

Q = 32 l/s

Head available = 50 metres

Length of pipeline = 4500 metres

Minimum PN rating of pipe available to withstand the 50 m static head is PN6.3.

Head loss per 100 m length of pipe is :

$$\frac{50}{4500} \times 100 = 1.11\text{m}/100\text{m}$$

Use Table 4.1 to select the SDR rating of PN6.3 class pipes in both PE80, and PE100 materials.

PE80 Material Option

PE80 PN6.3 pipe is SDR 21.

Use the SDR 21 flow chart, read intersection of discharge line at 32 l/s and head loss line at 1.11m/100m of pipe. Select the next largest pipe size.

This results in a DN200 mm pipe diameter.

PE100 Material Option

PE100 PN6.3 pipe is SDR 26.

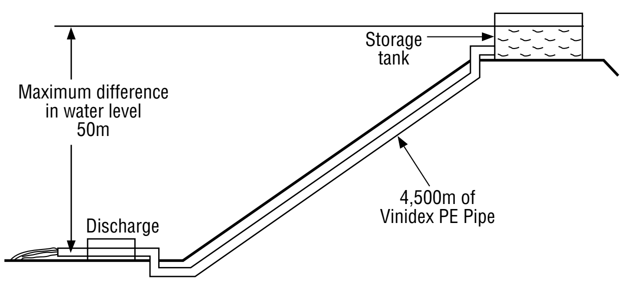
Use the SDR26 flow chart, read the intersection of discharge line at 32 l/s and head loss line at 1.11m/100m of pipe. Select the next largest pipe size.

This results in a DN180 mm pipe diameter.

Hence for this application, there are two options available, either :

1. DN 200 PE80 PN6.3 or
2. DN 180 PE100 PN6.3

Figure 4.1 Gravity Flow Example



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Example 2 - Pumped Main (refer Figure 4.2)

A line is required to provide 20 litres/second of water from a dam to a high level storage tank located 5000 metres away. The tank has a maximum water elevation of 100 m and the minimum water elevation in the dam is 70 m.

The maximum flow velocity is required to be limited to 1.0 metres/second to minimise water hammer effects.

The maximum head required at the pump = static head + pipe friction head + fittings form loss

1. Static head

= 100 - 70 = 30 m

2. Pipe friction head

Considering the data available, start with a PN6.3 class pipe.

PE80 Option

From Table 4.1, PE80 PN6.3 pipe is SDR21.

Use the SDR 21 flow chart, find the intersection of the discharge line at 20 l/s and the velocity line at 1 m/s. Select the corresponding or next largest size of pipe. Where the discharge line intersects the selected pipe size, trace across to find the head loss per 100m length of pipe.

This gives a value of 0.5m/100m.

Calculate the total friction head loss in the pipe:

$$\frac{0.5}{100} \times 5000 = 25\text{m}$$

Then from the flow chart, estimate the velocity of flow

This gives 1 m/s.

3. Fittings head losses

$$\text{Velocity Head} = \frac{v^2}{2g}$$

$$= \frac{1.0^2}{2 \times 9.81} = 0.05$$

From Figure 4.2, identify the type and number of different fittings used in the pipeline. Select the appropriate form factor value K for each fitting type from Table 4.9. Then:

Fitting	Form Factor K	Head Loss m
Foot valve	15.0	15 x 0.05 = 0.75
Gate valve	0.2	2 x 0.2 x 0.05 = 0.02
Reflux valve	2.5	2.5 x 0.05 = 0.125
90° elbow	1.1	4 x 1.1 x 0.05 = 0.220
45° elbow	0.35	2 x 0.35 x 0.05 = 0.035
Square outlet	1.0	1.0 x 0.05 = 0.050
Total fittings head loss		**= 1.2**

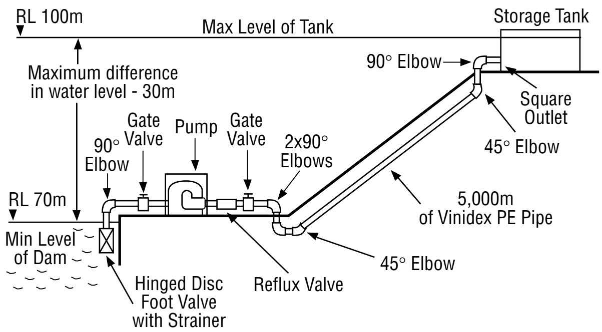
4. Total pumping head

= 30 + 25 + 1.2 = 56.2 m

allow 57 m.

Note: The example does not make any provision for surge allowance in pressure class selection.

Figure 4.2 Pumped Flow Example



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Part Full Flow

Non pressure pipes are designed to run full under anticipated peak flow conditions. However, for a considerable period the pipes run at less than full flow conditions and in these circumstances they act as open channels with a free fluid to air surface.

In these instances consideration must be given to maintaining a minimum transport velocity to prevent deposition of solids and blockage of the pipeline.

For pipes flowing part full, the most usual self cleansing velocity adopted for sewers is 0.6 metres/second.

Example 3. Determine flow velocity and discharge under part full flow conditions

Given gravity conditions:

Pipe DN 200 PE80 PN6.3

Mean Pipe ID 180 mm (Refer Table XX PE pipe dimensions, or AS/NZS 4130)

Gradient 1 in 100

Depth of flow 80 mm

Problem:

Find flow and velocity

Solution:

$$\text{Proportional Depth} = \frac{\text{Depth of flow}}{\text{Pipe ID}}$$

$$= \frac{80}{180} = 0.44$$

From Figure 4.3 Part Full Flow, for a proportional depth of 0.44, the proportional discharge is 0.4 and the proportional velocity if 0.95.

Refer to the Vinidex PE pipe flow chart for the SDR 21 pipe.

For a gradient of 1 in 100 full flow is 39 l/s and the velocity is 1.6 m/s.

Then, for part full flow

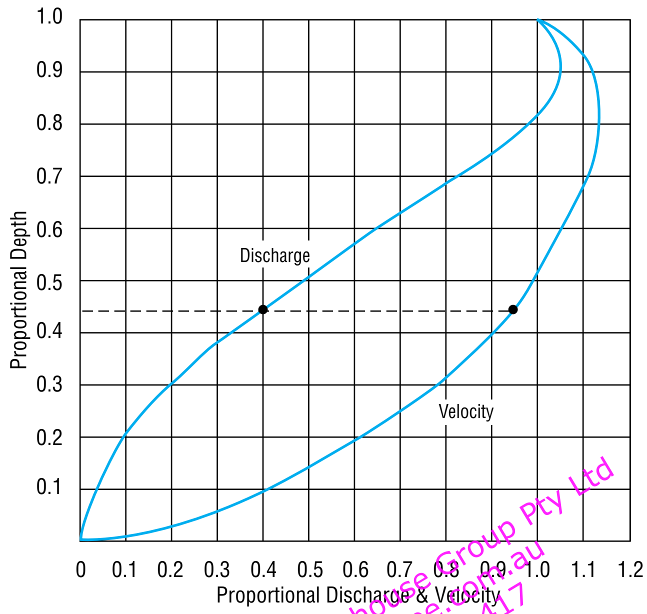
Discharge = 0.4 x 39

= 15.6 l/s

Velocity = 0.95 x 1.6

= 1.52 m/s

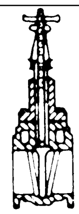
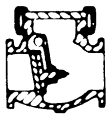
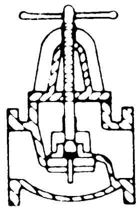
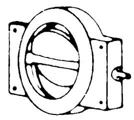
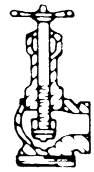
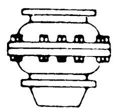
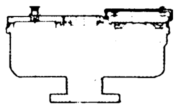
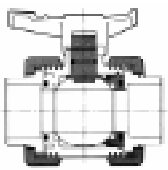
Figure 4.3 Part Full Flow



Resistance Coefficients

Table 4.9 Valves, Fittings and Changes in Pipe Cross-Section

Fitting Type		K
Pipe Entry Losses		
Square Inlet		0.50
Re-entrant Inlet		0.80
Slightly Rounded Inlet		0.25
Bellmouth Inlet		0.05
Pipe Intermediate Losses		
Elbows R/D < 0.6	45°	0.35
	90°	1.10
Long Radius Bends (R/D > 2)	$11^{1}/_{4}$°	0.05
	$22^{1}/_{2}$°	0.10
	45°	0.20
	90°	0.50
Tees		
(a) Flow in line		0.35
(b) Line to branch flow		1.00
Sudden Enlargements		
Ratio d/D		
0.9		0.04
0.8		0.13
0.7		0.26
0.6		0.41
0.5		0.56
0.4		0.71
0.3		0.83
0.2		0.92
<0.2		1.00
Sudden Contractions		
Ratio d/D		
0.9		0.10
0.8		0.18
0.7		0.26
0.6		0.32
0.5		0.38
0.4		0.42
0.3		0.46
0.2		0.48
<0.2		0.50

Fitting Type	K
Gradual Enlargements	
Ratio d/D q = 10° typical	
0.9	0.02
0.7	0.13
0.5	0.29
0.3	0.42
Gradual Contractions	
Ratio d/D q = 10° typical	
0.9	0.03
0.7	0.08
0.5	0.12
0.3	0.14
Valves	
Gate Valve (fully open) 	0.20
Reflux Valve 	2.50
Globe Valve 	10.00
Butterfly Valve (fully open) 	0.20
Angle Valve 	5.00
Foot Valve with strainer 	
hinged disc valve	15.00
unhinged (poppet) disc valve	10.00
Air Valves 	zero
Ball Valve 	0.10
Pipe Exit Losses	
Square Outlet	1.00
Rounded Outlet	1.00

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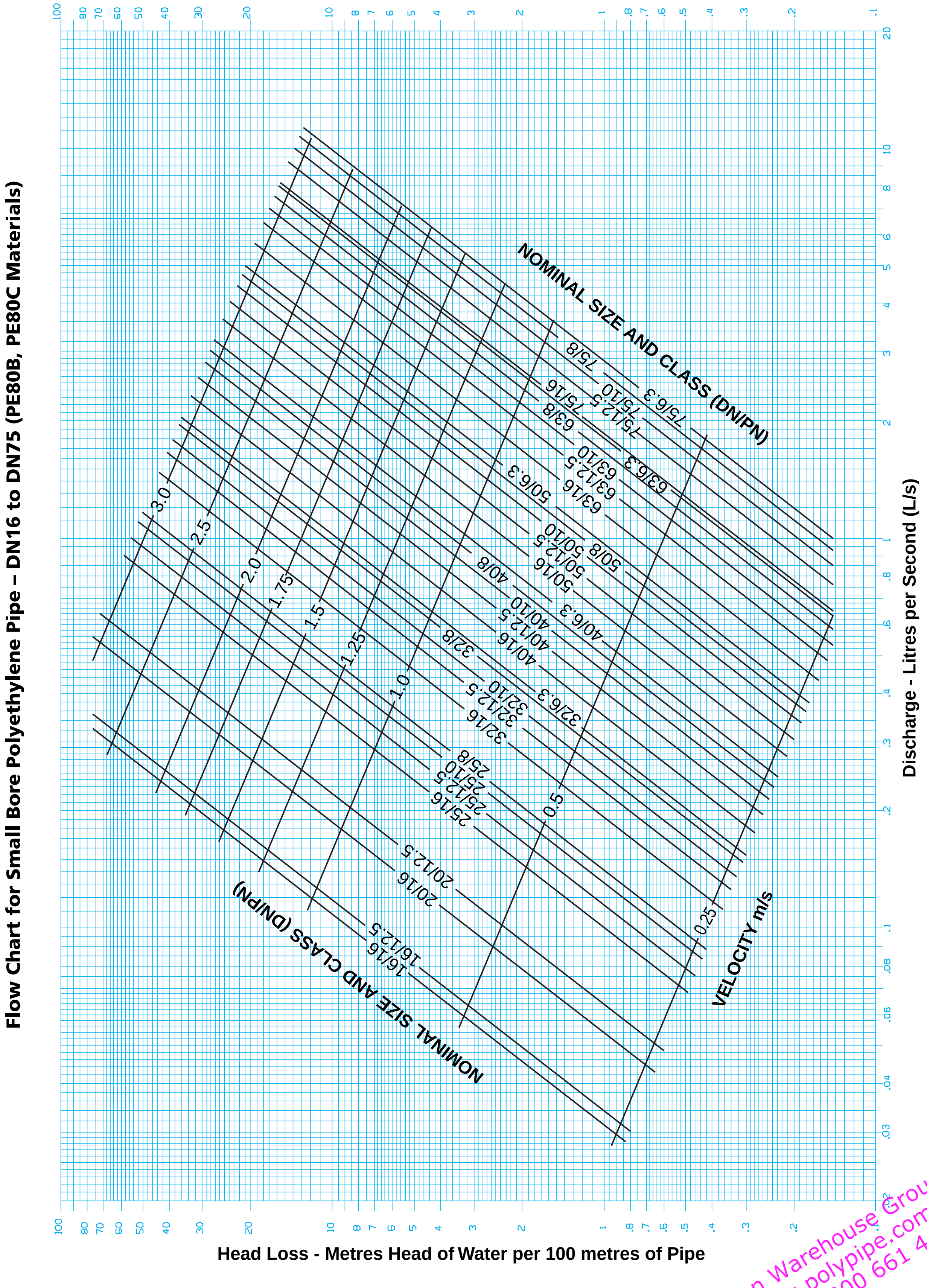
Flow Chart for Small Bore Polyethylene Pipe – DN16 to DN75 (PE80B, PE80C Materials)



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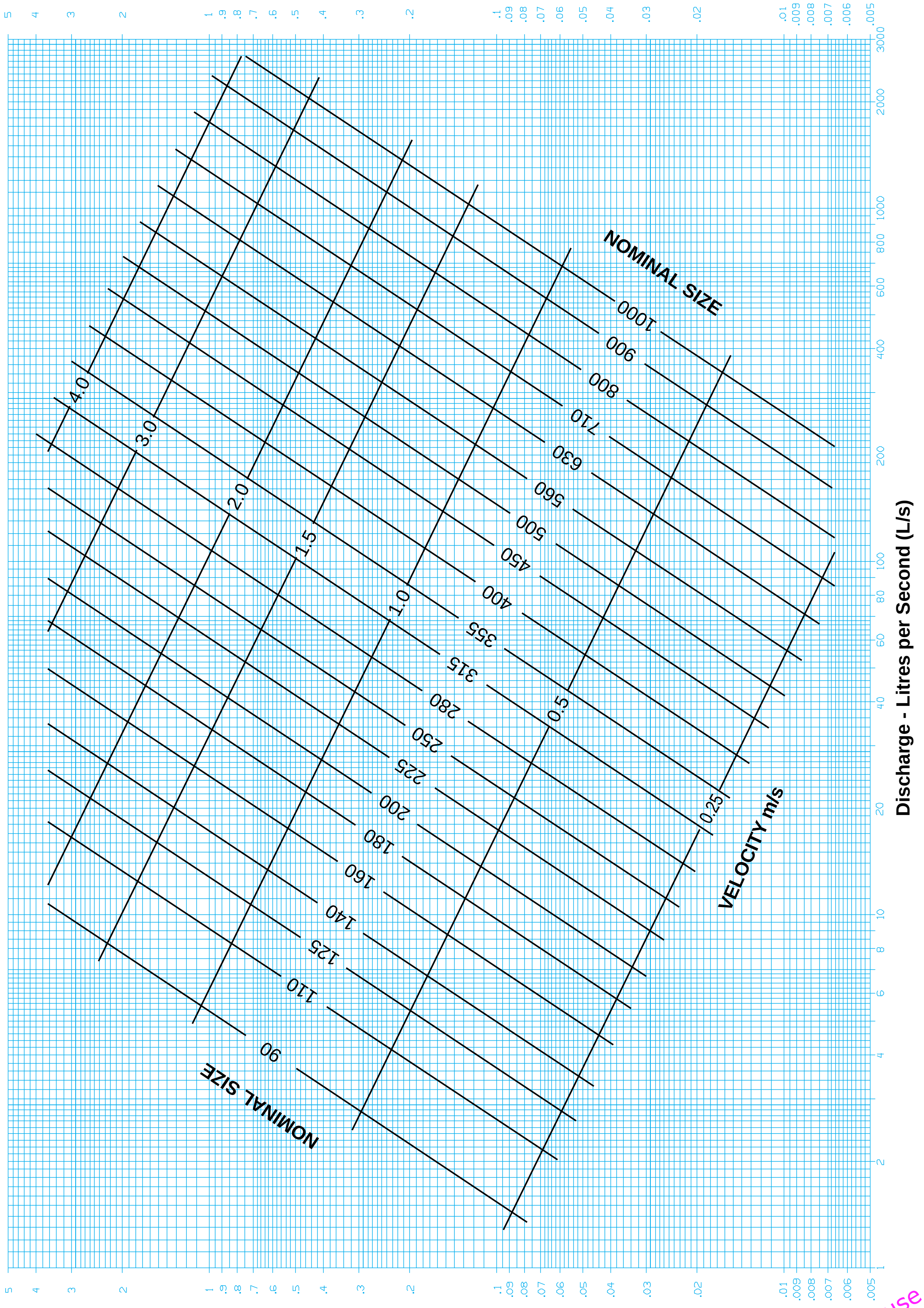
Flow Chart for Polyethylene Pipe – SDR 41
(PE80: PN3.2 & PE100: PN4)

Flow Chart for Polyethylene Pipe – SDR 41 (PE80: PN3.2 & PE100: PN4)



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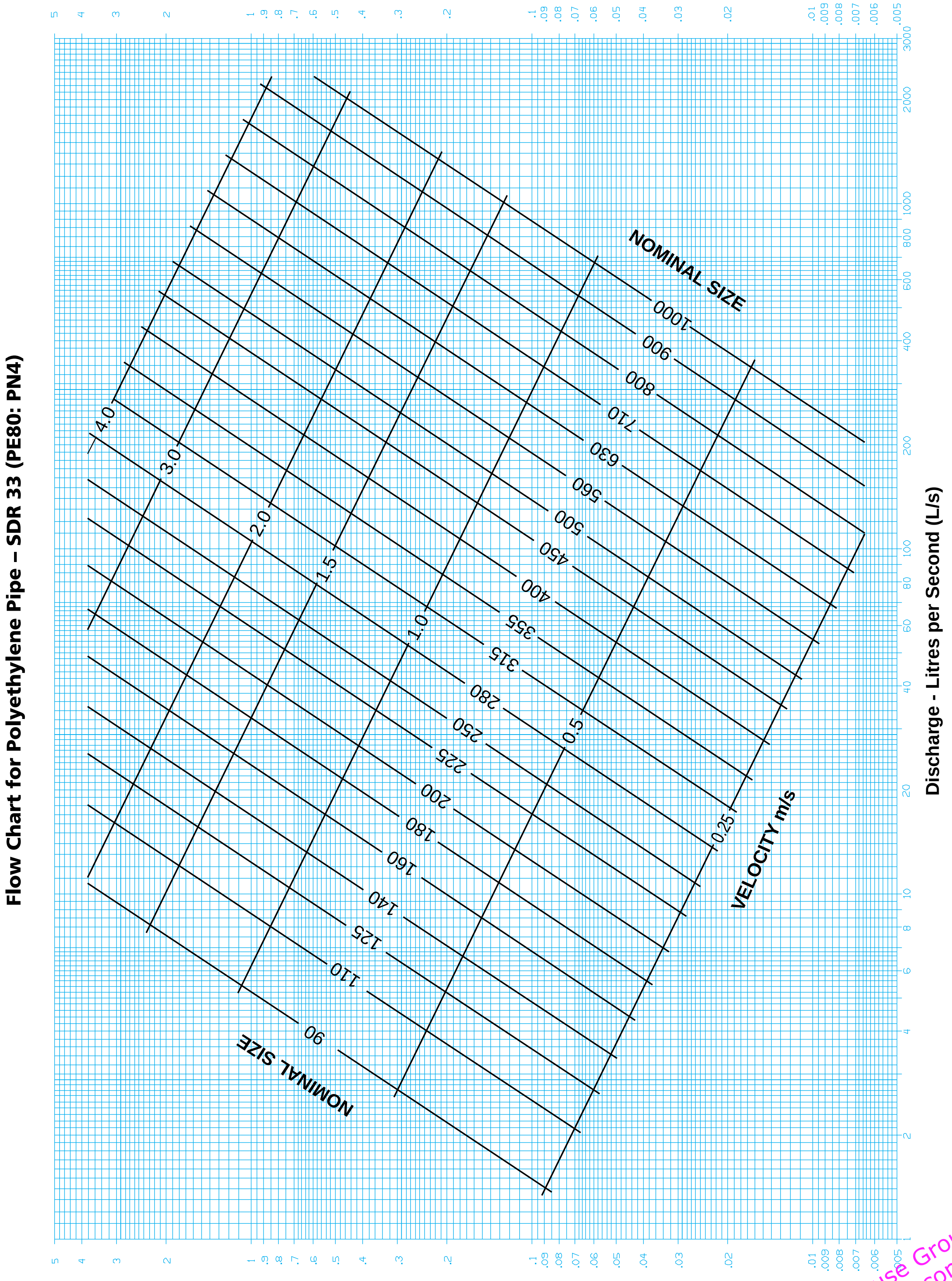
Flow Chart for Polyethylene Pipe – SDR 33 (PE80: PN4)



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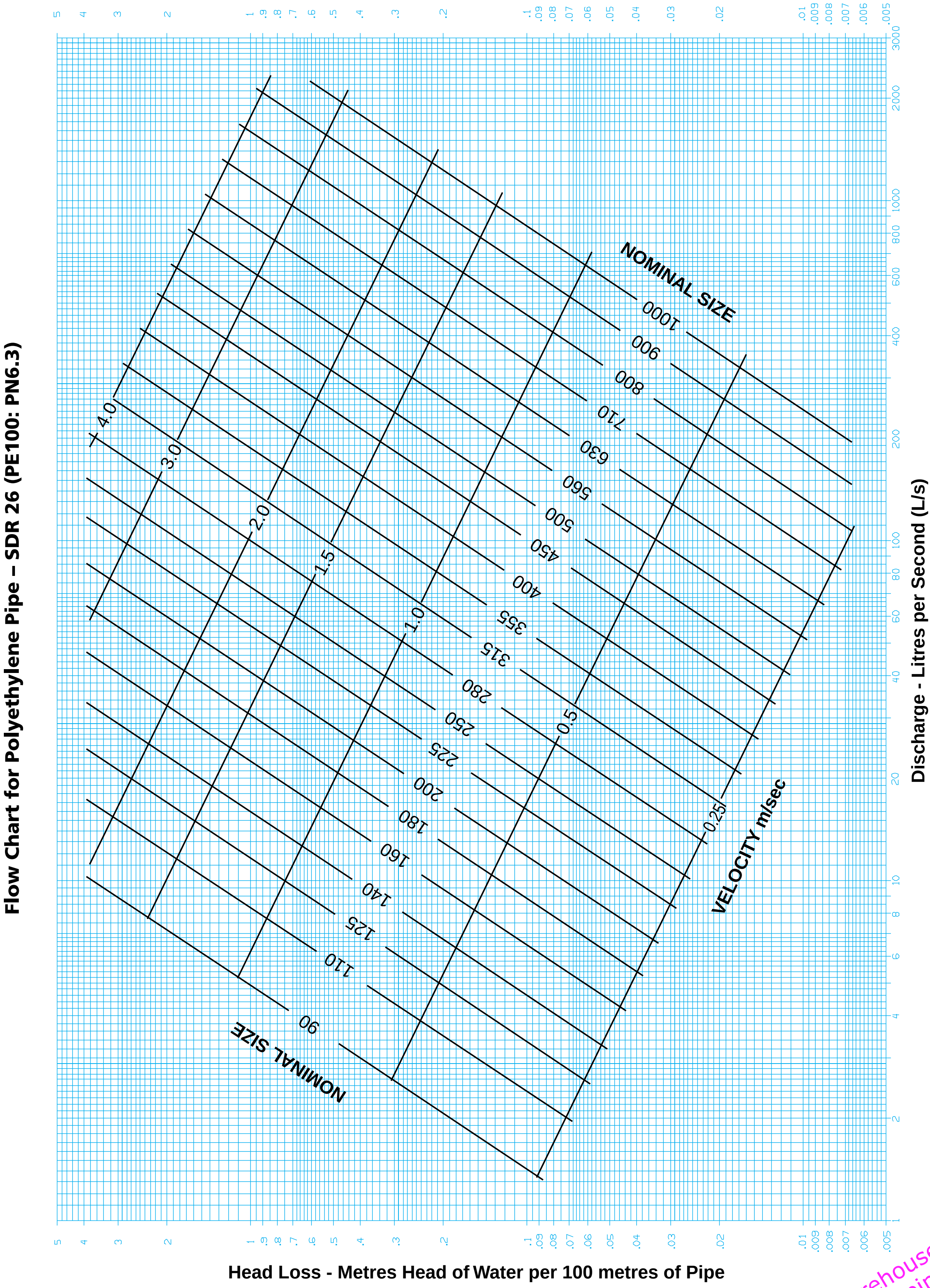
Flow Chart for Polyethylene Pipe – SDR 26 (PE100: PN6.3)



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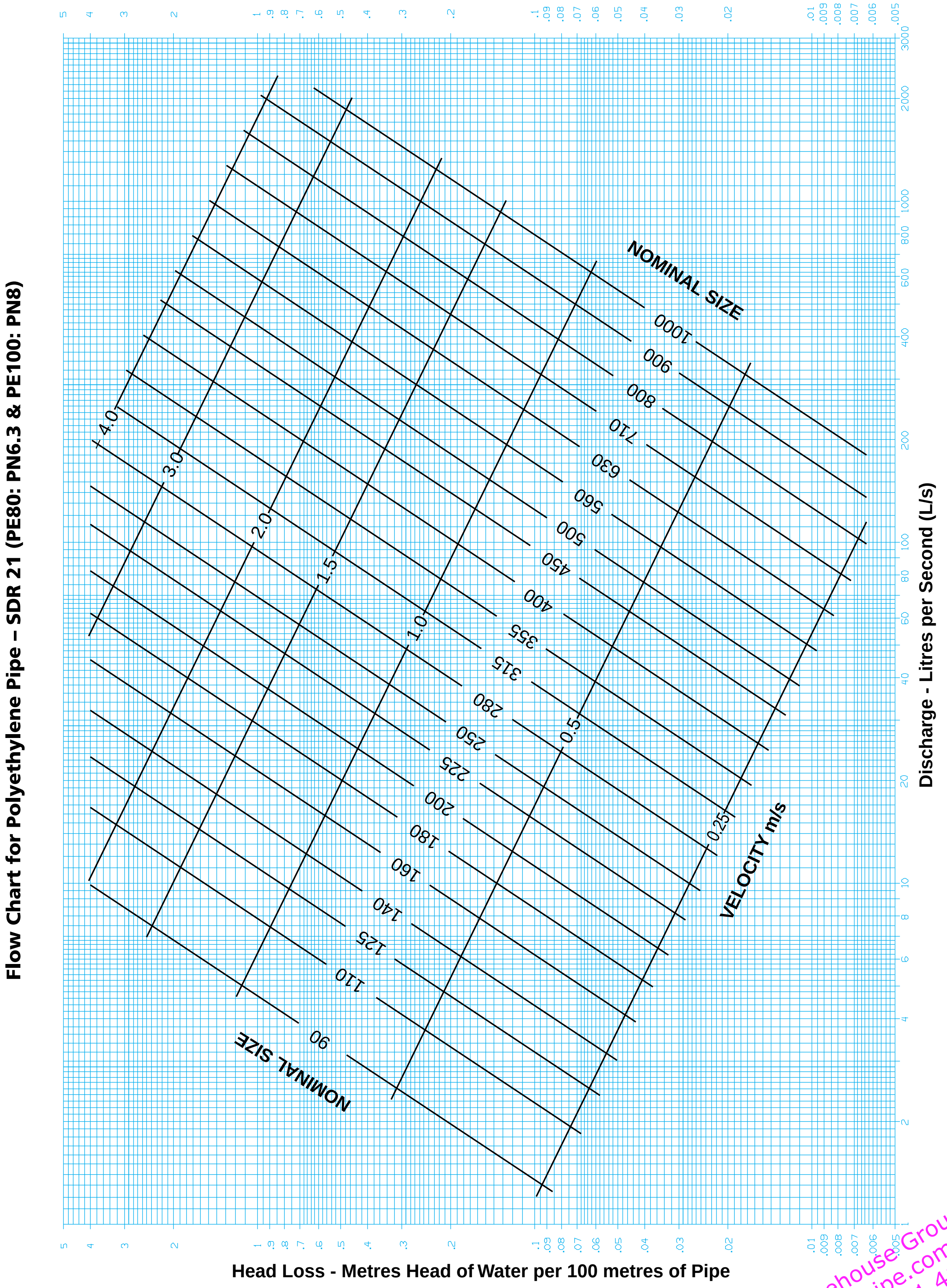
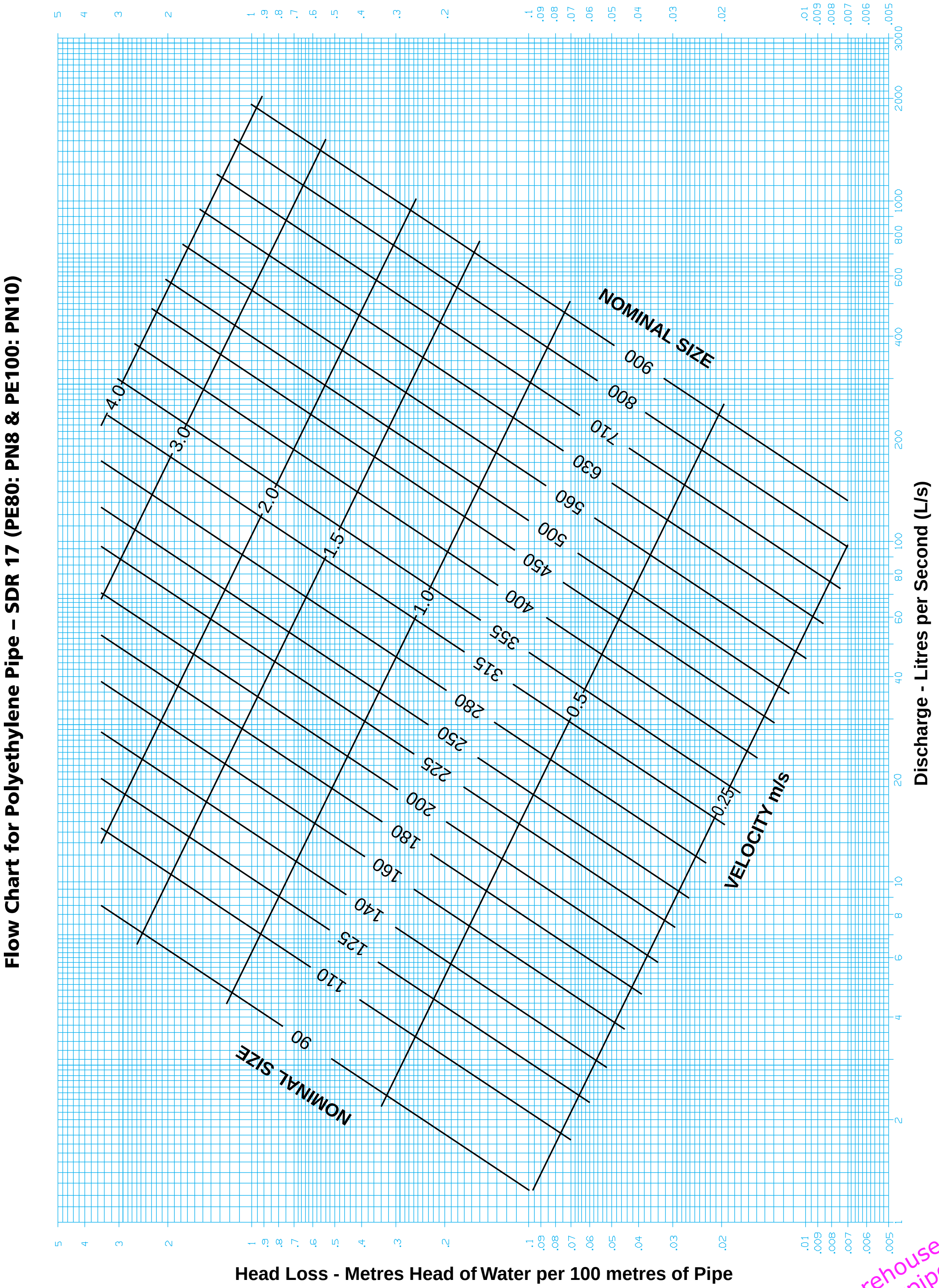
Flow Chart for Polyethylene Pipe – SDR 21
(PE80: PN6.3 & PE100: PN8)



Flow Chart for Polyethylene Pipe – SDR 17 (PE80: PN8 & PE100: PN10)



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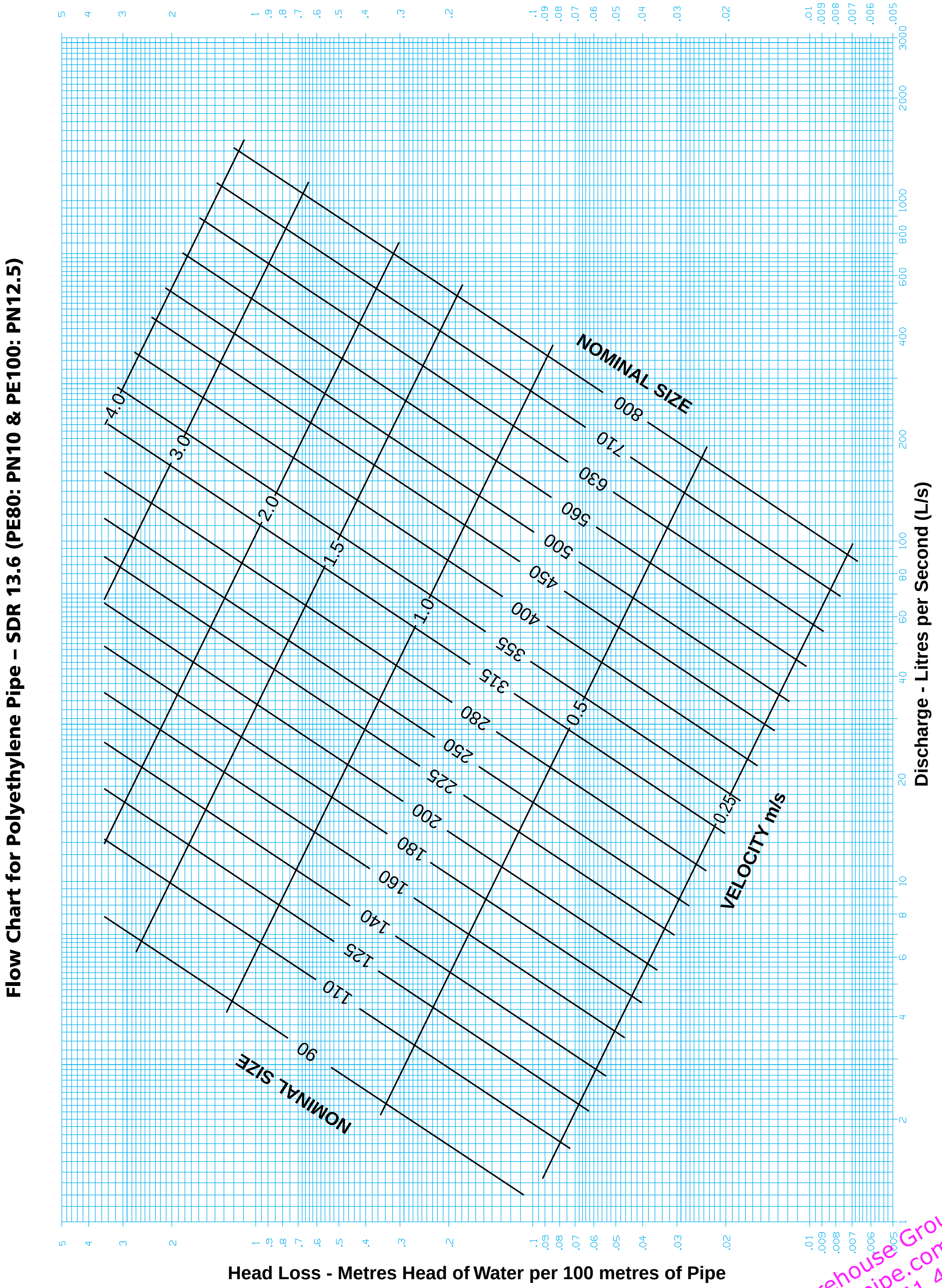
Flow Chart for Polyethylene Pipe – SDR 13.6 (PE80: PN10 & PE100: PN12.5)



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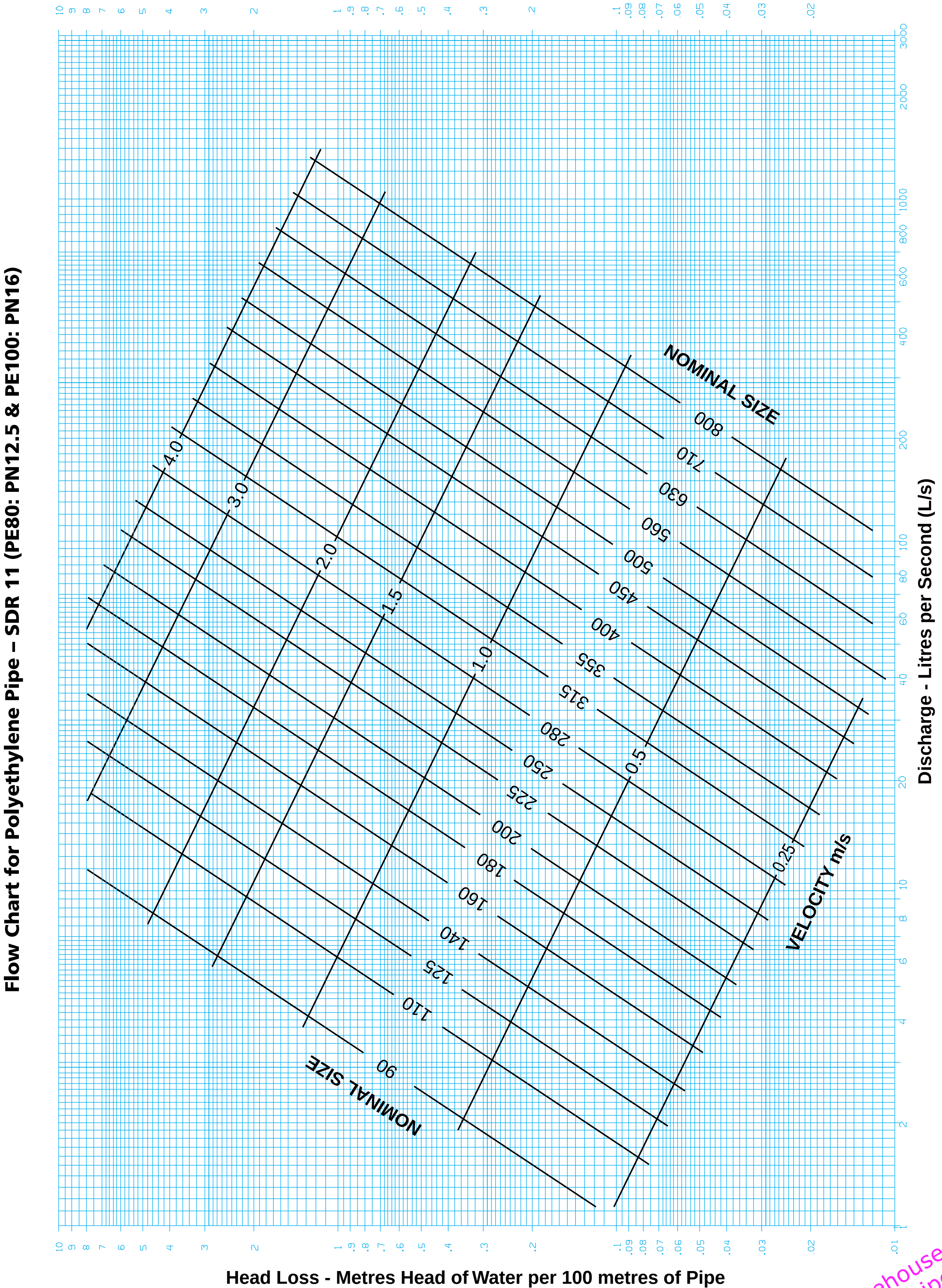
Flow Chart for Polyethylene Pipe – SDR 11 (PE80: PN12.5 & PE100: PN16)



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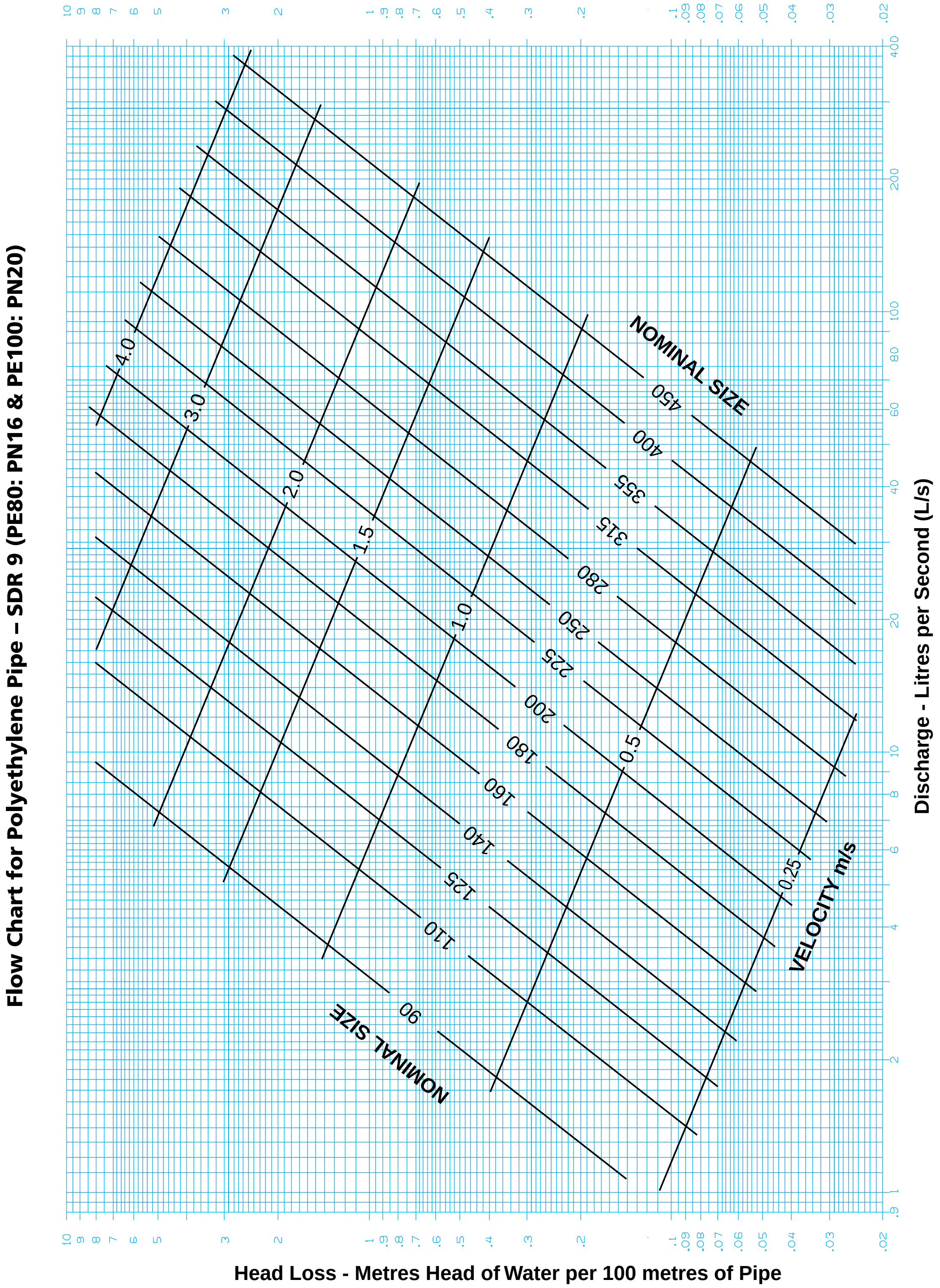
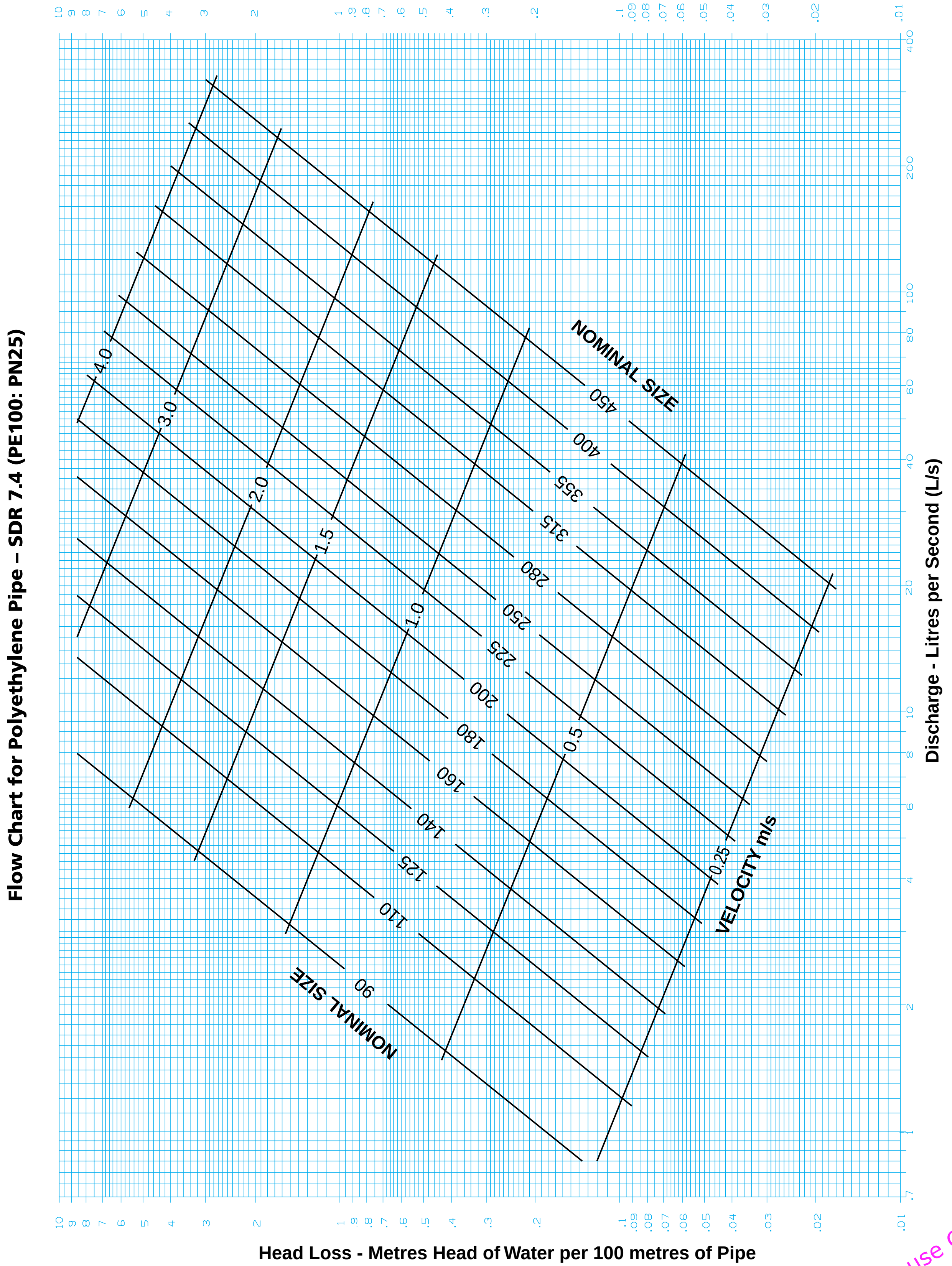
Flow Chart for Polyethylene Pipe – SDR 9 (PE80: PN16 & PE100: PN20)



Flow Chart for Polyethylene Pipe – SDR 7.4 (PE100: PN25)



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Surge & Fatigue

Surge, or 'water hammer', is a temporary change in pressure caused by a change in velocity of flow in the pipeline, whereas fatigue is the effect induced in the pipe or fitting by repeated surge events.

For Vinidex PE pipes to AS/NZS 4130, operating under the following limitations, it is not necessary to make specific allowance for fatigue effects:

(a) The maximum pressure in the pipe from all sources must be less than the pressure equivalent to the Classification of the pipe (PN).

and

(b) The amplitude between minimum and maximum pressure from all sources must not exceed the pressure equivalent to the Classification of the pipe (PN).

Care must be taken to ensure that the minimum pressure does not reach a level that may result in vacuum collapse (see External Pressure Resistance, page Design.36).

Surge may take the form of positive and/or negative pressure pulses resulting from change of flow velocity, such as arising from valve or pump operation. Such changes of flow velocity lead to induced pressure waves in the pipeline.

The velocity of the pressure wave, referred to as celerity (C), depends on the pipe material, pipe dimensions, and the liquid properties in accordance with the following relationship:

$$C = \left[W\left(\frac{1}{K} + \frac{SDR}{E} \right) \right]^{-0.5} \text{ x } 10^3 \text{ m/ sec}$$

where

W = liquid density (1000 kg/m³ for water)

SDR = Standard Dimension Ratio of the pipe

K = liquid bulk modulus (2150 MPa)

E = pipe material short term modulus (MPa) refer Table 4.8

The time taken for the pressure wave to travel the length of the pipeline and return is

$$t = \frac{2L}{C}$$

where:

t = time in seconds

L = length of pipeline

If the valve closure time t_c is less than t, the pressure rise due to the valve closure is given by:

$$P_1 = C.V$$

where:

P1 = pressure rise in kPa

v = liquid velocity in m/sec

If the valve closure time t_c is greater than t, then the pressure rise is approximated by:

$$P_2 = \left[\frac{t}{t_c} \right] P_1$$

This represents the case of a single pipeline with the flow being completely closed off. The pressure rises generated by flow changes in PE pipelines are the lowest generated in major pipeline materials due to the relatively low modulus values.

Further, as medium density materials have lower modulus values than high density materials, the pressure rise in PE80B materials will be lower than that in PE80C and PE100 materials.

Water hammer (surge) analysis of pipeline networks is complex and beyond the scope of this Manual. Where required, detailed analysis should be undertaken by experts.

Celerity

The surge celerity in a polyethylene pipeline filled with liquid can be determined by:

$$C = \left[W \left(\frac{1}{K} + \frac{SDR}{E} \right) \right]^{-0.5} x\ 10^3\ m/sec$$

where

W = liquid density (1000 kg/m^3 for water)

SDR = Standard Dimension Ratio of the pipe

K = liquid bulk modulus (2150MPa)

E = pipe material 'instantaneous' modulus (taken as 1000MPa for PE80B, 1200MPa for PE80C, 1500MPa for PE100)

Table 4.10 Surge Celerity

	Celerity m/s		
SDR	**MDPE (PE 80B)**	**HDPE (PE 80C)**	**HDPE (PE 100)**
41	160	170	190
33	170	190	210
26	190	210	240
21	220	240	260
17	240	260	290
13.6	270	290	320
11	300	320	360
9	330	350	390
7.4	360	390	430

Slurry Flow

General Design Considerations

The abrasion resistance characteristics and flexibility of Vinidex PE pipes make slurry flow lines, such as mine tailings, ideal applications for the material and such installations are in widespread use throughout Australia.

The transportation of Non Newtonian fluids such as liquids or liquid/liquid, liquid/solid mixtures or slurries is a highly complex process and requires a detailed knowledge of the specific fluid before flow rate calculations can be performed.

As distinct from water, many fluids regarded as slurries have properties which are either time or shear rate dependent or a combination of both characteristics. Hence it is essential for the properties of the specific fluid to be established under the operating conditions being considered for each design installation.

In addition to water flow, slurry flow design needs to take into account the potential for abrasion of the pipe walls, especially at changes of direction or zones of turbulence.

The most usual applications of Vinidex PE pipes involve liquid/solid mixtures and these must first be categorised according to flow type:

- Homogeneous Suspensions
- Heterogeneous Suspensions

Homogeneous Suspensions

Homogeneous suspensions are those showing no appreciable density gradient across the cross section of the pipe. These slurries consist of material particles uniformly suspended in the transport fluid.

Generally, the particle size can be used to determine the flow type and suspensions with particle sizes up to 20 microns can be regarded as homogeneous across the range of flow velocities experienced.

Heterogeneous Suspensions

Heterogeneous suspensions are those showing appreciable density gradients across the cross section of the pipe, and are those containing large particles within the fluid.

Suspensions containing particle sizes of 40 microns and above may be regarded as heterogeneous.

In addition to the fluid characterisations for both types, the tendency for solids to settle out of the flow means that a minimum flow velocity must be maintained.

This velocity, the Minimum Transport Velocity, is defined as the velocity at which particles are just starting to appear on the bottom of the pipe.

The flow in short length pipelines differs in that these lines may be flushed out with water before shut down of operations. Long length pipelines cannot be flushed out in the same way and the selection of operating velocities and pipe diameter needs to address this aspect.

The design of slurry pipelines is an iterative process requiring design assumptions to be made initially, and then repeatedly being checked and tested for suitability. The specific fluid under consideration requires full scale flow testing to be conducted to establish the accurate flow properties for the liquid/particle combinations to be used in the installed pipeline.

Without this specific data, the assumptions made as to the fluid flow behaviour may result in the operational pipeline being at a variance to the assumed behaviour. The principles of slurry pipeline design as outlined in the methods of Durand, Wasp, and Govier and Aziz are recommended in the selection of Vinidex PE pipes for these applications.

Note:

The published Vinidex PE pipe flow charts relate **ONLY** to water or other liquids which behave as Newtonian fluids.

They are not suitable for calculating the flow discharges of other fluids, including slurries.

For further information on slurry pipeline design, the designer is referred to such publications as Govier G.W. and Aziz K, *The Flow of Complex Mixtures in Pipes. Rheinhold, 1972.* and Wasp E.J. *Solid Liquid Flow - Slurry Pipeline Transportation. Trans Tech Publications. 1977.*

Pipe Wear

Polyethylene pipe has been a proven performer over many decades in resisting internal abrasion due to slurry. It is particularly resistant to abrasion from particles less than 500 microns in size depending on particle shape.

The abrasive wear of any slurry handling system is heavily dependent on the physical characteristics of the solids being transported. These characteristics include angularity, degree of particle attrition, angle of attack, velocity, and the concentration of solids in the transporting fluid.

With metal pipes, corrosive wear interacts synergistically with abrasive wear, producing rates of wear that can be many times greater than a simple combination of the two modes of wear. Corrosive attack on a piping material can lead to increasing roughness of the surface, loss of pressure and localised eddying, and hence increase the abrasive attack.

Factors Affecting Rates of Wear

The wall of polyethylene pipes are worn by contact with the solids particles. The principal causes of wear are as follows:

- Particle Size
- Particle Specific Gravity
- Velocity
- Angle of Attack

Particle Size

The size of the particle combined with the requisite velocity is one of the principal factors which contribute to wear. The rate of wear increases with particle size with very little wear occurring on polyethylene systems below 300 microns. Above this size the rate of wear will increase proportionally with particle size with the maximum practical D_{50} size around 1mm. Many researchers have attempted to develop relationships between particle size and rates of wear, however, these have not proven to be accurate due to the wide variation of slurry characteristics. The wear mechanism involved is not thoroughly understood, however, it is believed the higher impact energy resulting from a combination of particle mass and the high velocity required to transport this larger particle are the principal contributing factors.

Particle Specific Gravity

Similarly, the specific gravity will increase the mass of the particle resulting in increased wear. This is a result of the increased impact energy from the mass of the particle combined with the faster carrier velocity.

Velocity

A minimum velocity is required to provide the necessary uplift forces to keep a solid particle in suspension. This velocity also increases the impact energy of the particle against the wall of the pipe.

Angle of Attack

There are essentially two modes of wear, impingement and cutting. Cutting wear is considered to be caused by the low angle impingement of particles. In practice, cutting wear comprises a cutting action, and the accommodation of some of the energy of impact within the matrix of the material being worn. Hence, cutting wear also incorporates a component of deformation wear. The requirement for wear is that some of the solid particles must have sufficient energy to penetrate and shear a material, perhaps gouging fragments loose. As a result, a low modulus material such as polyethylene has very good resistance to cutting wear due to the resulting deformation upon impact. In the case of angular particles the cutting action is increased resulting in increased pipe wear.

The simple theory of abrasive wear suggests that specific wear (wear per unit mass transported) is proportional to normal force at the pipe wall. Therefore the wear rate will increase as the angle of attack to the pipe wall increases. The increase in angle will also increase the amount of energy with which the particle strikes the pipe wall. It is for this reason that accelerated wear is caused by:

i) **Fittings** which effect a change in the angle of flow such as tees and bends

ii) **Butt weld joints.** Butt weld internal beads will cause eddying which will result in increases in angle of attack of the particle to the pipe wall. As a result accelerated wear generally occurs immediately downstream of the bead. This is usually prominent in D_{50} particle sizes over 300 microns. For coarse particle slurries the internal bead should be removed.

iii) **Fittings joints.** At connections of mechanical fittings some misalignment of the mating faces may occur resulting in increased angles of attack of the particles.

iv) **Change in velocity.** Some compression fittings cause a reduction in the internal diameter of the pipe under the fitting resulting in turbulence. A mismatching valve bore will also cause turbulence. It is for this reason that the use of clear bore valves such as knife gate valves is preferred for slurry pipelines.

v) **Increased velocity.** High velocities are required to create sufficient turbulence for the suspension of heavy particles. This turbulence increases the angle of attack to the pipe wall, resulting in increased wear for large particles.

vi) **Insufficient velocity.** When a system is operated near its settling velocity, the heavier particles migrate towards the lower half of the pipe cross section. This will cause a general increase in pipe wear in this area. If saltation/moving bed occurs, then the heavy particles will impact against the pipe bottom, causing an accelerated wave profile wear. Should deposition occur on the floor of the pipe, then the particles above this deposition will cause the maximum amount of wear as they interact with the flow. This is characterised by the formation of wave marks on the 5 and 7 o'clock position of the pipe.

Maintenance and Operation

To reduce the cost of wear on a pipeline asset it is general practice to rotate the pipes at the appropriate intervals, this is particularly important when transporting sand slurries. In this respect mechanical joints are useful, although re-welding of pipes over 500mm has been preferred in some cases to reduce capital costs. These mechanical joints are usually installed at every 20m pipe length to assist the pipe rotation process and also permit clearance of blockages.

Slurry pipelines are usually operated as close to the critical settling velocity as practical to reduce operating costs. Unfortunately, if an increase in particle size occurs, then saltation will commence increasing friction loss eventually resulting in a blockage. Other factors that cause blockages are increases in solids concentration, loss of pump pressure due to power failure, or pump impellor wear. Polyethylene pipelines may be cleared of blockages by clear water pumping provided they have been installed on flat even ground. Sudden vertical 'V' bends with angles over 10° may cause an accumulation of solids in the bore, preventing clearing by clear water pumping. If vertical bends are unavoidable then they should be installed with mechanical joints to permit their easy removal for clearing.

Fittings

A range of mechanical joints are available for polyethylene slurry pipelines. They include stub flanges and backing rings, Hugger couplings, shouldered end/Victaulic couplings, compression couplings and rubber ring joint fittings.

References

The Transportation of Flyash and Bottom Ash in Slurry Form, C G Verkerk

Relative Wear Rate Determinations for Slurry Pipelines, C A Shook, D B Haas, W H W Husband and M Small

Warman Slurry Pumping Handbook, Warman International Ltd.

Pneumatic Flow

Vinidex PE pipe systems are ideal for the transmission of gases both in the high and low pressure range.

The use of compressible liquids in PE pipes requires a number of specific design considerations as distinct from the techniques adopted in the calculation of discharge rates for fluids such as water.

In particular:

- Compressed air may be at a higher temperature than the surrounding ambient air temperature, especially close to compressor line inlets, and the pressure rating of the PE pipes require temperature re rating accordingly.

  For air cooled compressors, the delivered compressed air temperature averages 15°C above the surrounding air temperature. For water cooled compressors, the delivered compressed air temperature averages 10°C above the cooling water temperature.
- For underground applications where the PE pipes are exposed to ambient conditions, the surrounding air temperature may reach 30°C, and the pipe physical properties require adjustment accordingly.
- High pressure lines must be mechanically protected from damage especially in exposed installations.
- Valve closing speed must be reduced to prevent a build up of pressure waves in the compressible gas flow.
- Where gaseous fuels such as propane, natural gas, or mixtures are carried, the gas must be dry and free from liquid contamination which may cause stress cracking of the PE pipe walls.
- Vinidex PE pipes should not be connected directly to compressor outlets or air receivers. A 21 metre length of metal pipe should be inserted between the air receiver and the start of the PE pipe to allow for cooling of the compressed air.
- Dry gases, and gas/solids mixtures may generate static electrical charges and these may need to be dissipated to prevent the possibility of explosion. PE pipes will not conduct electrical charges, and conducting inserts or plugs must be inserted into the pipe to complete an earthing circuit.
- Compressed air must be dry, and filters installed in the pipeline to prevent condensation of lubricants which can lead to stress cracking in the PE pipe material.

System Design Guidelines for the Selection of Vinidexair Compressed Air Pipelines

It is customary to find the Inside Diameter of the pipe by using formulas such as shown below. The formulas used are generally for approximation purposes only, surmising that the temperature of the compressed air corresponds roughly to the induction temperature. An acceptable approximation is obtained through the following equation:

$$d = \sqrt[5]{\frac{450.L_E.Q^{1.85}}{\Delta p.p}}$$

where

d = Pipe Internal Diameter in mm

L_E = Pipe Length in m

Q = Volumetric Flowrate in L/s

Dp = Pressure Decrease in bar

p = Working Pressure in bar

The use of a nomogram is a quicker and easier method to source information (see Figure 4.4). In this nomogram the Pressure Decrease (Δp) is indicated in bar, the Working Pressure (p) in bar, the Volumetric Flowrate (Q) in L/s, the Pipe Length (L_E) in m, and the Pipe Nominal Diameter DN.

The advantage of using the nomogram is that no further conversion factors are required for pipe sizing. Also, when four of the parameters are known the fifth can be determined by reading directly from the nomogram.

Example for the use of the air-line nomogram (Figure 4.4) to determine the required pipe size

Working Pressure	7 bar
Volumetric Flowrate	30 L/s
Nominal length	200 m
Pressure Decrease	0.05 bar

1 Utilising the above operating figures, proceed to mark those positions around the perimeter of the nomogram.

2 Locate the separation line between (Δp) & (p). (See base of nomogram.)

3 Commencing at the lower right hand side of the nomogram draw a line up from the Working Pressure (p) to the line indicating the Volumetric Flowrate (Q).

4 Using point (3) draw a diagonal line to the separation line.

5 Go to top of nomogram and use the point indicating the Length of Pipe and draw a line down to meet horizontal line from point (4).

6 Move to the Pressure Decrease in the Pipe (Δp) at the bottom of nomogram and draw a vertical line up to meet the diagonal drawn from point (5).

7 The Nominal Diameter of Pipe can now be found by reading from point (6) across to the left hand side of the nomogram. From this example DN63 pipe should be selected. If the completed nomogram falls between two sizes of pipe, always use the larger size.

Correction factors for fittings

Table 4.11 indicates the approximate pressure loss for fittings in terms of an equivalent length of straight pipe in metres. For each pipeline fitting, add the equivalent length of pipe to the original length of pipeline. This length is used for the calculation of the equation above or for the nomogram, Figure 4.4.

Table 4.11 Pressure Loss for Fittings

Fitting	equivalent pipe length in m						
	DN 20	DN 25	DN 32	DN 40	DN 50	DN 63	DN 90
socket welding joint	0.2	0.2	0.3	0.4	0.5	0.6	1.1
45° bend	0.2	0.3	0.4	0.6	0.9	1.2	2.3
90° bend	0.4	0.7	1.0	1.3	1.8	2.3	4.5
tees	0.8	1.4	1.9	2.4	2.8	3.8	7.5
reducer	0.3	0.4	0.5	0.6	0.7	0.9	2.1

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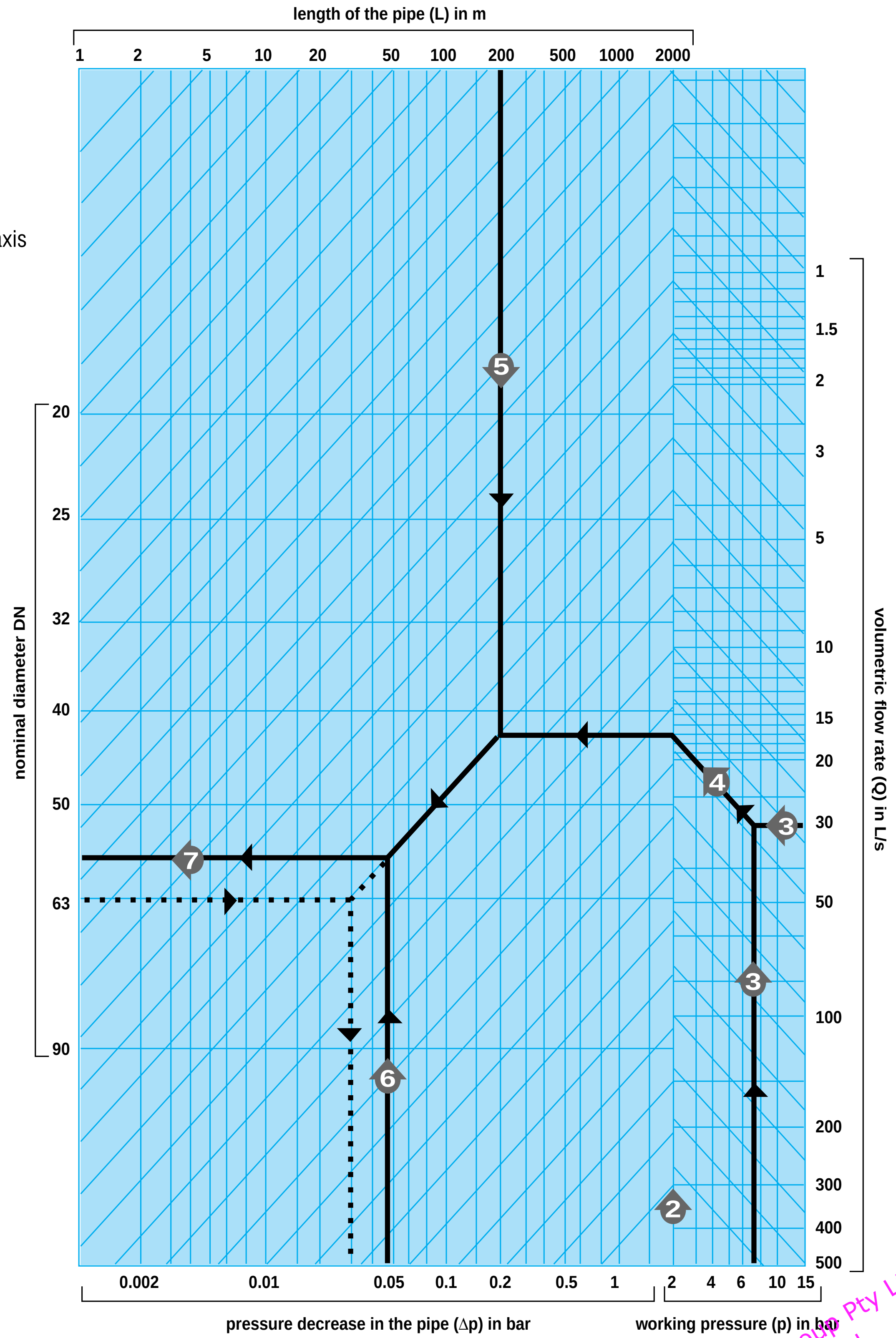
Figure 4.4
Compressed Air
Flow Nomogram

Sources:

Feldmann, K.H.:
Druckluftverteilung in der Praxis
(Munchen 1985)

Atlas Copco :
information sheets



Expansion and Contraction

Expansion and contraction of PE pipes occurs with changes in the pipe material service temperature.

This is in common with all pipe materials and in order to determine the actual amount of expansion or contraction, the actual temperature change, and the degree of restraint of the installed pipeline need to be known.

For design purposes, an average value of 2.0×10^{-4}/°C for Vinidex PE pipes may be used.

The relationship between temperature change and length change for different PE grades is as shown in Figure 4.5.

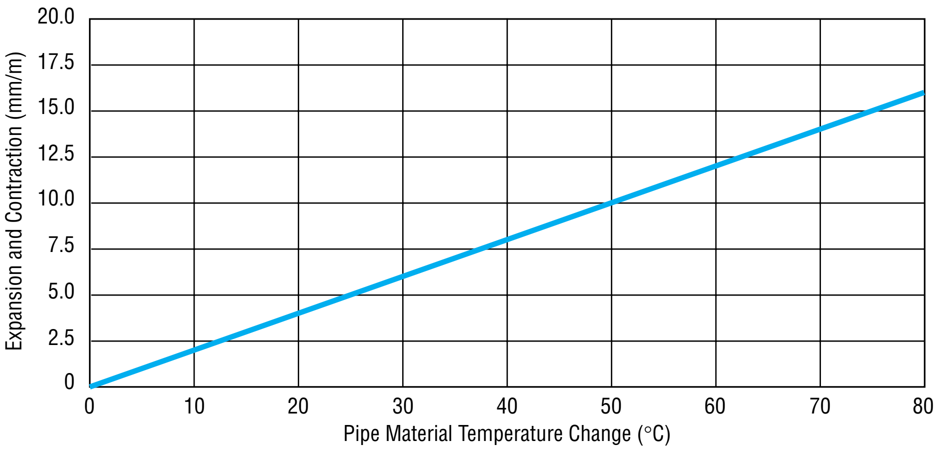
Worked Example

A 100 metre long PE80C pipeline operates during the day at a steady temperature of 48°C and when closed down at night cools to an ambient temperature of 18°C. What allowance for expansion/contraction must be made?

1. The temperature change experienced = 48 - 18 = 30°C.
2. The thermal movement rate (Figure 4.5) in mm/m for 30°C = 6.0 mm/m.
3. The total thermal movement is then 6.0 x 100 = 600 mm.

Where pipes are buried, the changes in temperature are small and slow acting, and the amount of expansion/contraction of the PE pipe is relatively small. In addition, the frictional support of the backfill against the outside of the pipe restrains the movement and any thermal effects are translated into stress in the wall of the pipe.

Figure 4.5 Thermal Expansion and Contraction for PE



Accordingly, in buried pipelines the main consideration of thermal movement is during installation in high ambient temperatures.

Under these conditions the PE pipe will be at it's maximum surface temperature when placed into a shaded trench, and when backfilled will undergo the maximum temperature change, and hence thermal movement.

In these cases the effects of temperature change can be minimised by snaking the pipe in the trench for small sizes (up to DN110) and allowing the temperature to stabilise prior to backfilling.

For large sizes, the final connection should be left until the pipe temperature has stabilised.

Above ground pipes require no expansion/contraction considerations for free ended pipe or where lateral movement is of no concern on site. Alternatively, pipes may be anchored at intervals to allow lateral movement to be spread evenly along the length of the pipeline.

Where above ground pipes are installed in confined conditions such as industrial or chemical process plants the expansion/contraction movement can be taken up with sliding expansion joints. Where these cannot be used due to the fluid type being carried (such as slurries containing solid particles) the advice of Vinidex design engineers should be sought for each particular installation.

External Pressure Resistance

The possibility of external pressure (buckling) being the controlling design condition must be evaluated in the design of PE pipelines.

All flexible pipe materials can be subject to buckling due to external pressure and PE pipes behave in a similar fashion to PVC and steel pipes.

For pipe of uniform cross-section, the critical buckling pressure (P_c) can be calculated as follows:

$$P_c = \frac{2380 \cdot E}{(SDR - 1)^3}$$

where

P_c = critical buckling pressure, kPa

E = modulus, MPa from Table 4.8

SDR = pipe SDR from Table 4.1

As the modulus is temperature and time dependent, the advice of Vinidex engineers should be sought for appropriate values.

Where ovality exists in the PE pipes, the effective value of the critical buckling pressure will be reduced.

The reduction in P_c for various levels of initial ovality are as follows:

Ovality %	0	1	2	5	10
Reduction	1.0	0.99	0.97	0.93	0.86

Where pipes are buried and supported by backfill soil, the additional support (P_b) may be calculated from:

$$P_b = 1.15 \ (P_c E')^{0.5}$$

Where E´ = soil modulus from AS/NZS2566 - Buried Flexible Pipelines.

Tabulations of the value of E´ for various combinations of soil types and compactions are contained in AS/NZS2566.

The value of P_c calculated requires a factor of safety to be applied and a factor of 1.5 may be applied for those conditions where the negative pressure conditions can be accurately assessed.

Where soil support is taken into account then a factor of 3 is more appropriate due to the uneven nature of soil support.

In general terms, PN10 PE pipe should be used as a minimum for pump suction line installations.

Where installation conditions potentially lead to negative pressures, consideration may need to be given to modification of construction technique. For example, ducting pipes may need to be sealed and filled with water during concrete encasement.

In operation, fluid may be removed from the pipeline faster than it is supplied from the source. This can arise from valve operation, draining of the line or rupture of the line in service. Air valves must be provided at high points in the line and downstream from control valves to allow the entry of air into the line and prevent the creation of vacuum conditions. On long rising grades or flat runs where there are no significant high points or grade changes, air valves should be placed at least every 500-1000 metres at the engineer's discretion.

Soil Description	E´ MPa
Gravel – graded	20
Gravel – single size	14
Sand and coarse-grained soil with less than 12% fines	14
Coarse-grained soil with more than 12% fines	10
Fine-grained soil (LL<50%) with medium to no plasticity and containing more than 25% coarse-grained particles	10
Fine-grained soil (LL<50%) with medium to no plasticity and containing less than 25% coarse-grained particles	10
Fine-grained soil (LL<50%) with medium to high plasticity	NR

Trench Design

Minimum Cover

The recommended minimum cover depths for Vinidex PE pipes are listed in Table 4.12.

These cover depths are indicative only, and specific installations should be evaluated in accordance with AS/NZS 2566 - Buried Flexible Pipelines.

The minimum cover depths listed may be reduced where load reduction techniques are used, such as load bearing beams, concrete slabs, conduit sleeves, or increased backfill compaction.

Trench Widths

In general practice, the trench width should be kept to the minimum that enables construction to readily proceed. Refer to Figures 4.6 and 4.7.

The trench width used with PE pipe may be reduced from those used with other pipe types by buttwelding, or electrofusion jointing above ground, and then feeding the jointed pipe into the trench. Similarly, small diameter pipe in coil form can be welded or mechanically jointed above ground and then fed into the trench.

The minimum trench width should allow for adequate tamping of side support material and should be not less than 200mm greater than the diameter of the pipe. In very small diameter pipes this may be reduced to a trench width of twice the pipe diameter.

Table 4.12 Minimum Cover

Installation Condition		Cover over Pipe Crown (mm)
Open country		300
Traffic Loading	No pavement	450
	Sealed pavement	600
	Unsealed pavement	750
	Construction equipment	750
	Embankment	750

The maximum trench width should be restricted as much as possible, depending on the soil conditions. This is necessary to reduce the cost of excavation, and to develop adequate side support.

Where wide trenches or embankments are encountered, then the pipe should be installed on a 75 mm layer of tamped or compacted bedding material as shown on the cross section diagrams. Where possible a sub trench should be constructed at the base of the main trench to reduce the soil loads developed. AS/NZS 2566 provides full details for evaluating the loads developed under wide trench conditions.

Bedding

PE Pipes should be bedded on a continuous layer, 75 mm thick, of materials complying with the following requirements:

- Sand, free from rocks or other hard or sharp objects retained on a 13.2mm sieve.
- Gravel or crushed rock of suitable grading up to a max. size of 15mm.
- The excavated material, free from rocks and broken up such that it contains no clay lumps greater than 75mm which would prevent adequate compaction.

Side Support

Material used for side support should comply with the requirements of the bedding materials.

The side support material should be evenly tamped in layers of 75 mm for pipes up to 250mm diameter, and 150 mm for pipes of diameters 315mm and above.

Compaction should be brought evenly to the design value required by AS/NZS 2566 for the specific installation.

Backfill

Once the sidefill has been placed and compacted as required over the top of the pipe, backfill material may be placed using excavated material.

Trench backfills should not be used as a dump for large rocks, builders debris, or other unwanted site materials.

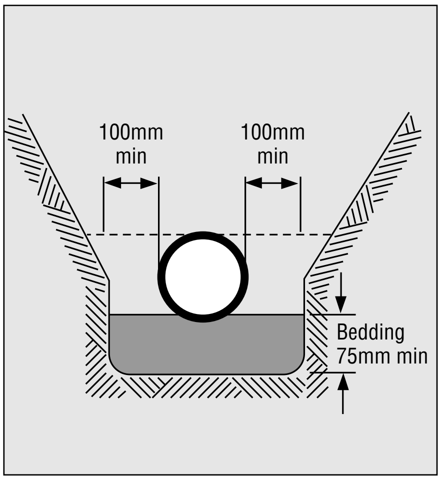


Figure 4.6
Wide Trench Condition

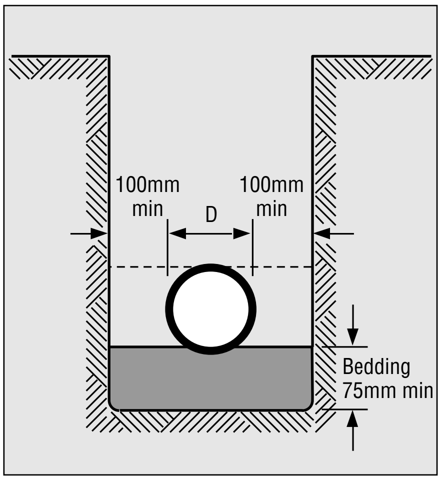


Figure 4.7
Narrow Trench Condition

Allowable Bending Radius

Vinidex PE pipes are flexible in behaviour, and can be readily bent in the field.

In general terms, a minimum bending radius of 33 x outside diameter of the pipe (33D) can be adopted for PE80C, and PE100 material pipes, whilst a radius of 20 x outside diameter of the pipe (20D) can be adopted for PE63, and PE80B material pipes during installation.

This flexibility enables PE pipes to accommodate uneven site conditions, and, by reducing the number of bends required, cuts down total job costs.

For certain situations, the designer may wish to evaluate the resistance to kinking or the minimum bending radius arising from strain limitation. The long term strain from all sources should not exceed 0.04 (4%).

When bending pipes there are two control conditions:

1. Kinking in pipes with high SDR ratios.
2. High outer fibre strain in high pressure class pipes with low SDR ratios.

For condition 1

The minimum radius to prevent kinking (R_k) may be calculated by:

$$R_k = \frac{SDR\ (SDR-1)}{1.12}$$

For condition 2

The minimum radius to prevent excess strain (R_e) may be calculated by:

$$R_e = \frac{D}{2}\,\varepsilon$$

where

ε = outer fibre strain (maximum allowable = 0.04)

D = mean Di (mm)

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Deflection Questionnaire

AS/NZS 2566 Deflection Calculation for Buried Flexible Pipes

The following questionnaire is to assist designers in the calculation of deflection for buried flexible pipe.

Please photocopy before completing this form.
Retain this master for future use.
Complete all information and forward to your nearest Vinidex office – refer over leaf.

Company ______________________________

Name ______________________________

Phone ______________ Fax ______________ Email ______________

PIPE DETAILS

Pipe Size and SDR or Class ______________________________

Pipe Material (ie. PE80/PE100) ______________________________

TRENCH DETAILS

Depth of Cover (from crown) ______________________________

Width (at pipe) ______________________________

Depth to Water Table (if above pipe) ______________________________

LOADS

Live Load ______________________________

Dead Load ______________________________

SOIL TYPE

Native Soil ______________________________

Embedment Material ______________________________

Degree of Compaction ______________________________

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Vinidex Locations

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Mildura
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Brisbane & Export
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Thrust Block Supports

PE pipes and fittings joined by butt welding, electrofusion, or other end load bearing joint system do not normally require anchorage to withstand loads arising from internal pressure and flow.

For joint types which do not resist end loads, plus fabricated fittings which incorporate welded PE pipe segments, anchorage support must be provided in order to prevent joint or fitting failure. In addition, appurtenances such as valves, should be independently supported in order to prevent excessive shear loads being transferred to the PE pipe.

Static Pressure Thrust

$$R = \frac{2PA \cdot \sin\phi \cdot 10^{-3}}{2}$$

where

R = resultant thrust (kN)

P = pressure (MPa)

A = area of pipe cross section (mm^2)

ϕ = angle of fitting (degrees)

For blank ends, tees and valves

$$R = PA\ 10^{-3}$$

For reducers

$$R = P(A_1 - A_2)\ 10^{-3}$$

Velocity (Kinetic) Thrust

The velocity or kinetic thrust applies only at changes of direction.

$$R = \frac{2\ w\ a\ V^2 \cdot \sin\phi \cdot 10^{-9}}{2}$$

where

w = fluid density (kg/m^3)

a = inside pipe cross section area (mm^2)

V = flow velocity (m/s)

The velocity thrust is generally small in comparison to the pressure thrust.

The pressure used in the calculations should be the maximum working, or test pressure, applied to the line.

Bearing Loads of Soils

The thrust developed must be resisted by the surrounding soil. The indicative bearing capacities of various soil types are tabulated below:

The figures in the table below are for horizontal thrusts, and may be doubled for downward acting vertical thrusts. For upward acting vertical thrusts, the weight of the thrust block must counteract the developed loads.

In shallow (<600mm) cover installations or in unstable conditions of fill, the soil support may be considerably reduced from the values tabulated, and a complete soil analysis may be needed.

Soil Type	Safe Bearing Capacity (N/m^2)
Rock and sandstone (hard thick layers)	100×10^5
Rock- solid shale and hard medium layers	90×10^4
Rock- poor shale, limestone	24×10^4
Gravel and coarse sand	20×10^4
Sand- compacted, firm, dry	15×10^4
Clay- hard, dry	15×10^4
Clay- readily indented	12×10^4
Clay/Sandy loam	9×10^4
Peat, wet alluvial soils, silt	Nil

Thrust Block Size Calculations

1. Establish the maximum pressure to be applied to the line
2. Calculate the thrust developed at the fitting being considered
3. Divide (2) by the safe bearing capacity of the soil type against which the thrust block must bear.

Worked Example

What bearing area of thrust block is required for a 160 mm PN12.5 90° bend in hard, dry clay?

1. Maximum working pressure of PN12.5 pipe is 1.25 MPa.

   Test pressure is 1.25 x WP

   = 1.56 MPa.

2. $R = \frac{2\,PA\,.\sin\phi.10^{-3}}{2}$

   $= 3.8 \times 10^{-4}$ N

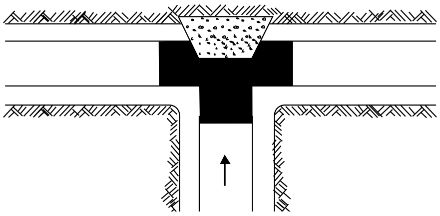
3. Bearing capacity of hard, dry clay is 15×10^4 N/m^2

$$\text{Bearing area of thrust block} = \frac{3.8 \times 10^4}{15 \times 10^4}$$

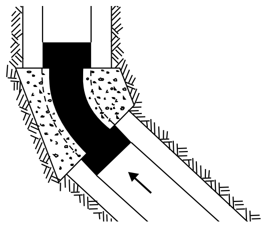
$$= 0.25\text{m}^2$$

Thrust blocks may be concrete or timber. Where cast insitu concrete is used, an adequate curing period must be provided to allow strength development in the concrete before pressure is introduced to the pipeline. Where timber blocks are used, test pressures may be introduced immediately, but care needs to be taken to ensure that the blocks will not rot and will not be attacked by termites or ants.

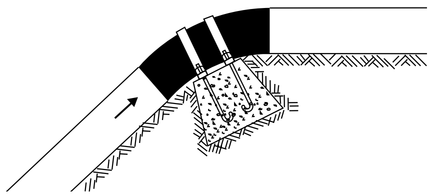
Figure 4.8 Thrust Blocks



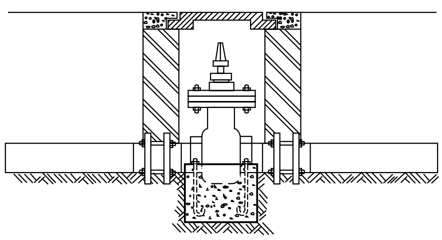
Tee anchorage



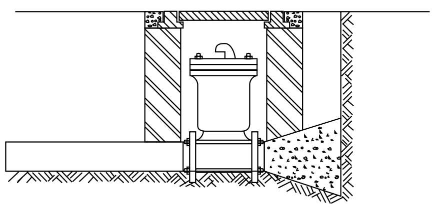
Bend in horizontal plane anchorage



Bend in vertical plane anchorage



Valve anchorage



Closed end and hydrant anchorage

Electrical Conductivity

Vinidex PE pipes are non conductive and cannot be used for electrical earthing purposes or dissipating static electricity charges.

Where PE pipes are used to replace existing metal water pipes, the designer must consider any existing systems used for earthing or corrosion control purposes. In these cases the appropriate electrical supply authority must be consulted to determine their requirements.

In dry, dusty, or explosive atmospheres, potential generation of electricity must be evaluated and static dissipation measures adopted to prevent any possibility of explosion.

Vibration

Direct connection to sources of high frequency such as pump outlet flanges should be avoided. All fabricated fittings manufactured by cutting and welding techniques must be isolated from vibration.

Where high frequency vibration sources exist in the pipeline, the PE sections should be connected using a flexible joint such as a repair coupling, expansion joint, or wire reinforced rubber bellows joint. When used above ground such joints may need to be restrained to prevent pipe end pullout.

Heat Sources

PE pipes and fittings should be protected from external heat sources which would bring the continuous pipe material service temperature above 80°C.

Where the PE pipes are installed above ground, the protection system used must be resistant to ultra violet radiation and the effects of weathering, PE pipes running across roofing should be supported above the roof sheeting in order to prevent temperature build up.

See Table 4.7 Temperature Rating Table.