PRESSURE RATING

WL Plastics HDPE Pressure Pipe – Determining Pressure Ratings for Applications

Short-Term and Long-Term Performance

WL Plastics pressure rated HDPE pipe is manufactured from polyethylene materials that are custom engineered to provide the unique properties needed for pressure pipe. Pipes must withstand short-term and long-term loads from the application, and here polyethylene is unique because its strength under load depends on the magnitude of the load and how long the load is applied.

Under short-term loads, polyethylene typically reacts in a resilient, ductile-elastic manner, but the reaction to long-term loads is very different. Short-term ultimate strength is characterized by tremendous ductile elongation (necking down and stretching) and then failure in the elongated area. In contrast, long-term ultimate strength is characterized by cracks that grow slowly through the pipe wall (slow crack growth). Short-term and long-term characteristics are so different that short-term properties cannot be used to predict long-term performance.

Polyethylene pressure pipes are designed for years of continuous internal pressure. To predict (rate) long-term internal pressure performance, polyethylene pipe materials must undergo long-term testing and analysis to determine the internal pressure the pipe can withstand at an operating temperature. For polyethylene pressure pipe materials, testing and analysis is conducted in accordance with ASTM and PPI standards[1].

The hydrostatic design stress, HDS, is a maximum long-term design stress at an operating temperature for the material. For polyethylene pressure pipe materials, the HDS is typically determined at 73°F and 140°F. Table 1 shows HDS ratings for WL Plastics HDPE materials.

Table 1 HDS – WL Plastics HDPE

	HDS at 73°F	*HDS at 140°F*
PE4710	1000 psi	630 psi
PE3608/PE3408	800 psi	400 psi

[1] ASTM D1598 Time-to-Failure of Plastic Pipe Under Constant Internal Pressure; ASTM D2837 Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials; PPI TR-3 Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

Internal Pressure Rating

The equations below are used to determine a long-term internal pressure rating by taking into account the material's long-term strength, operating temperature, environmental (application) conditions and pipe size.

$$PR = \frac{2\,HDS\,f_T\,f_E}{(DR-1)} \qquad (1)$$

Where

- PR = pressure rating, psi.
- HDS = hydrostatic design stress at 73°F, psi
- f_T = operating temperature multiplier
- f_E = environmental design factor
- DR = pipe dimension ratio

$$DR = \frac{D}{t} \qquad (2)$$

- D = pipe outside diameter, in
- t = pipe minimum wall thickness, in

Polyethylene material strength is inversely dependent on temperature, that is, its strength decreases at elevated temperatures. Eq. 1 relates strength to temperature using a Table 2 operating temperature multiplier, f_T. When determining an application pressure rating, the f_T for the highest application operating temperature is typically used for a conservative rating.

Table 2 Operating Temperature Multiplier, f_T

Maximum Operating Temperature		*Multiplier, f_T*	
°F	*°C*	*PE4710*	*PE3608 PE3408*
≤40*	≤4	1.23	1.31
>40 ≤60*	>4 ≤16	1.16	1.21
>60 ≤80	<16 ≤27	1.00	1.00
>80 ≤90	>27 ≤32	0.93	0.90
>90 ≤100	>32 ≤38	0.87	0.82
>100 ≤110	>38 ≤43	0.81	0.75
>110 ≤120	>43 ≤49	0.76	0.68
>120 ≤130	>49 ≤54	0.70	0.61
>130 ≤140	>54 ≤60	0.65	0.54

* Multipliers based on midrange temperature. For water distribution and transmission applications, multipliers for 60°F (16°C) and lower temperatures are not used.

The application "environment" within and outside the pipe is factored into Eq. 1 using a Table 3 environmental design factor, f_E.

Table 3 Environmental Design Factor, f_E

Factor, f_E	*Environmental and Applications Conditions,*
1.00	Liquids that are chemically benign to polyethylene such as potable and process water, municipal sewage, wastewater, reclaimed water, salt water, brine solutions, glycol/antifreeze solutions, alcohol; Buried pipes for gases that are chemically benign to polyethylene such as dry natural gas (in Class 1 locations where U.S. and Canadian Federal Regulations[2] do not limit pressure), methane, propane, butane, carbon dioxide, hydrogen sulfide.
0.64	Buried pipes for compressed air, oxygen, and other oxidizing gases at ambient temperature (≤80°F/≤27°C); U.S. Only – Buried pipes for fuel gases such as natural gas, LP gas, propane, butane in gas distribution systems and Class 2, 3 or 4 locations where U.S. Federal Regulations limit pipe pressure to the lesser of 125 psi for ≤12-in or 100 psi for >12-in. or the design pressure rating.
0.80	Canada Only – Buried pipes for fuel gases such as natural gas, LP gas, propane, butane in distribution systems subject to Canadian Federal and Provincial Regulations.
0.50	Permeating or solvating liquids in the pipe or the surrounding soil such as gasoline, fuel oil, kerosene, crude oil, diesel fuel, liquid hydrocarbon fuels, vegetable and mineral oils.

Pipe size is factored into Eq. 1 through the dimension ratio, DR, Eq. 2. For a given DR, wall thickness increases or decreases in direct proportion to the outside diameter. DR is convenient because it remains constant as pipe size varies. That is, a 2" DR 11 pipe and a 24" DR 11 pipe have the same pressure rating for the same application temperature and environment. A side benefit is that minimum wall thickness is easily determined by dividing the pipe diameter by the DR.

Internal Pressure Rating Examples

1. Determine the long-term pressure rating for DR 11 WL Plastics PE4710 HDPE pipe transporting brine water at 125°F.

$$PR = \frac{2(1000)(0.70)(1.00)}{(11-1)} = 140\ psi$$

2. Determine the long-term pressure rating for DR 17 WL Plastics PE3608/PE3408 HDPE pipe transporting crude oil at 115°F.

$$PR = \frac{2(800)(0.75)(0.50)}{(17-1)} = 37.5\ psi$$

3. Determine the long-term pressure rating for 8" IPS DR 9 WL Plastics PE3608/PE3408 HDPE pipe carrying 70°F natural gas in a US Class 3 location.

$$PR \le 125\ psi \text{ or } \frac{2(800)(1.00)(0.64)}{(9-1)} = 128\ psi$$

The calculation yields 128 psi, but US Federal Regulations limit the pressure rating to 125 psi for 12" IPS and smaller pipes (100 psi max for >12" IPS through 24" IPS.)

4. Determine the long-term pressure rating for DR 11 WL Plastics HDPE pipe on the surface transporting compressed air at 120°F.

Per Table 3, this application is not recommended.

Liquid Flows

Short term internal pressure surges such as water hammer result from instantaneous liquid flow velocity changes. These conditions are accommodated above the long-term internal pressure rating by short-term physical capabilities.

For distribution and transmission of liquids such as water or water-borne slurries, the standard surge pressure allowance above the long-term design pressure rating is:

$$P_{SA} = 1.00 \times PR \tag{3}$$

Surge pressures typically result from instantaneous liquid velocity changes from conditions such as firefighting, slurry blockage or component failure.

Liquid flow velocity is determined using

$$V = \frac{1.283\,Q}{\pi\,D_i^2} \tag{4}$$

Where

V = velocity, ft/sec.
Q = flow quantity, U.S. gal/min
D_i = pipe average inside diameter, in

$$D_i = D - 2.12\frac{D}{DR} \tag{5}$$

(Note – D_i is an average pipe ID for flow estimation purposes only. Actual pipe ID will vary depending on specification dimensions and tolerances. Consult specifications or measure actual pipe ID for devices such as stiffeners that install in the pipe bore.)

When a surge pressure event such as water hammer occurs in a pipe, the velocity of the pressure surge is dependent on the instantaneous elastic modulus of the pipe material and pipe dimensions.

$$a = \frac{4660}{\sqrt{1+\frac{k\,D_i}{E\,t}}} \tag{6}$$

Where

a = pressure wave velocity, ft/sec
k = fluid bulk modulus, psi
= 300,000 psi for water

[2] U.S. – Department of Transportation Title 49 Code of Federal Regulations Part 192; Canada – CSA Z662 Clause 13.

E	=	instantaneous dynamic elastic modulus of pipe material, psi
	=	150,000 psi for HDPE per AWWA M55

The surge pressure, P_S, caused by a sudden change in liquid flow velocity is:

$$P_S = \frac{a(\Delta v)}{2.31g} \quad (7)$$

Where

P_S	=	surge pressure, psi
Δv	=	sudden velocity change, ft/sec
g	=	gravitational acceleration. ft/sec^2
	=	32.2 ft/sec^2

(Note – The sudden velocity change, Δv, must occur within the critical time, 2L/a, where 'L' is the pipe length in feet and 'a' is the pressure wave velocity (Eq. 6). A surge pressure does not occur if the time required for the velocity change exceeds the critical time.)

During steady pressure operation, the maximum operating pressure, MOP, should not exceed the long-term pressure rating, and during a pressure surge event, the total internal pressure should not exceed the long-term pressure rating plus the pressure surge allowance. Table 4 shows the approximate instantaneous water velocity change to produce a surge pressure equal to the surge pressure allowance. If the potential velocity change results in a surge pressure that is higher than the pressure surge allowance, the MOP is reduced or pipe having a higher pressure rating is used (Eq. 9), with the difference between PR and MOP added to P_{SA}.

During steady pressure operation,

$$PR \geq MOP \quad (8)$$

And during a surge pressure event,

$$PR + P_{SA} \geq MOP + P_S \quad (9)$$

Table 4 Pressure Rating, Surge Allowance and Corresponding Velocity Change for Water

DR	*PR, psi*		*P_{SA}, psi*		*Δv, ft/sec*	
	PE4710	*PE3608 PE3408*	*PE4710*	*PE3608 PE3408*	*PE4710*	*PE3608 PE3408*
7	333	267	333	267	17.6	14.1
7.3	317	254	317	254	17.3	13.8
9	250	200	250	200	15.5	12.4
11	200	160	200	160	13.9	11.1
13.5	160	128	160	128	12.5	10.0
17	125	100	125	100	11.1	8.9
21	100	80	100	80	10.0	8.0
26	80	64	80	64	8.9	7.2
32.5	63	51	63	51	8.0	6.4

kPa = psi x 6.895; m/sec = ft/sec x 0.305

External Pressure/Vacuum Resistance

Circumferentially applied external pressure or internal vacuum or a combination of external pressure and internal vacuum will attempt to flatten the pipe. Freestanding non-pressure pipe in surface, sliplining, submerged and like applications is not supported by embedment or other external confinement that can significantly enhance resistance to flattening from external pressure. The resistance of freestanding pipe to flattening from external pressure depends on wall thickness (pipe DR), elastic properties (time and temperature dependent elastic modulus and Poisson's ratio), and roundness.

$$P_{CR} = \frac{2 E f_O}{\left(1-\mu^2\right)}\left(\frac{1}{DR-1}\right)^3 \quad (9)$$

Where

P_{CR}	=	flattening resistance limit, psi
E	=	modulus of elasticity, psi
μ	=	Poisson's Ratio
	=	0.35 for short-term stress
	=	0.45 for long-term stress
f_O	=	roundness factor
DR	=	pipe dimension ratio, (Eq. 2)

$$P_{AL} = \frac{P_{CR}}{N} \quad (10)$$

Where

P_{AL}	=	safe external pressure, psi
N	=	safety factor (typically ≥ 2)

Table 5 Roundness Factor, f_O

% Deflection	*f_O*	*% Deflection*	*f_O*
0	1.00	6	0.52
1	0.92	7	0.48
2	0.88	8	0.42
3	0.78	9	0.39
4	0.70	≤10	0.36
5	0.62		

Table 6 Modulus of Elasticity for PE4710 and PE3608/PE3408 HDPE

Temperature, °F (°C)	*Modulus of Elasticity for Load Time, kpsi (MPa)*						
	Short-term	10 h	100 h	1000 h	1 y	10 y	50 y
-20 (-29)	300.0 (2069)	140.8 (971)	125.4 (865)	107.0 (738)	93.0 (641)	77.4 (534)	69.1 (476)
0 (-18)	260.0 (1793)	122.0 (841)	108.7 (749)	92.8 (640)	80.6 (556)	67.1 (463)	59.9 (413)
40 (4)	170.0 (1172)	79.8 (550)	71.0 (490)	60.7 (419)	52.7 (363)	43.9 (303)	39.1 (270)
60 (16)	130.0 (896)	61.0 (421)	54.3 (374)	46.4 (320)	40.3 (278)	33.5 (231)	29.9 (206)
73 (23)	110.0 (758	57.5 (396	51.2 ((353)	43.7 (301)	38.0 (262)	31.6 (218)	28.2 (194)
100 (38)	100.0 (690)	46.9 (323)	41.8 (288)	35.7 (246)	31.0 (214)	25.8 (178)	23.0 (159
120 (49)	65.0 (448)	30.5 (210)	27.2 (188)	23.2 (160)	20.2 (139)	16.8 (116)	15.0 (103)
140 (60)	50.0 (345)	23.5 (162)	20.9 (144)	17.8 (123)	15.5 (107)	12.9 (89)	11.5 (79)

Table 7 Safe External Pressure for HDPE, P_{AL}, psi, by Load Duration and Service Temperature[1]

Load Duration	*Max. Service Temp., °F*	*DR*									
		7	*7.3*	*9*	*11*	*13.5*	*15.5*	*17*	*21*	*26*	*32.5*
½ Day	≤ 40	328.4	283.7	138.5	70.9	36.3	23.3	17.3	8.9	4.5	2.3
	> 40 ≤ 60	251.0	216.8	105.9	54.2	27.8	17.8	13.2	6.8	3.5	1.7
	> 60 ≤ 80	236.6	204.4	99.8	51.1	26.2	16.8	12.5	6.4	3.3	1.6
	> 60 ≤ 100	193.0	166.7	81.4	41.7	21.3	13.7	10.2	5.2	2.7	1.3
	> 100 ≤ 120	125.5	108.4	53.0	27.1	13.9	8.9	6.6	3.4	1.7	0.9
	> 120 ≤ 140	96.7	83.5	40.8	20.9	10.7	6.9	5.1	2.6	1.3	0.7
42 Days	≤ 40	274.9	237.4	116.0	59.4	30.4	19.5	14.5	7.4	3.8	1.9
	> 40 ≤ 60	210.1	181.5	88.6	45.4	23.2	14.9	11.1	5.7	2.9	1.5
	> 60 ≤ 80	197.9	170.9	83.5	42.7	21.9	14.0	10.4	5.3	2.7	1.4
	> 60 ≤ 100	161.7	139.6	68.2	34.9	17.9	11.5	8.5	4.4	2.2	1.1
	> 100 ≤ 120	105.1	90.7	44.3	22.7	11.6	7.4	5.5	2.8	1.5	0.7
	> 120 ≤ 140	80.6	69.6	34.0	17.4	8.9	5.7	4.3	2.2	1.1	0.6
1 Year	≤ 40	238.6	206.1	100.7	51.5	26.4	16.9	12.6	6.4	3.3	1.6
	> 40 ≤ 60	182.5	157.6	77.0	39.4	20.2	12.9	9.6	4.9	2.5	1.3
	> 60 ≤ 80	172.1	148.6	72.6	37.2	19.0	12.2	9.1	4.6	2.4	1.2
	> 60 ≤ 100	140.4	121.3	59.2	30.3	15.5	9.9	7.4	3.8	1.9	1.0
	> 100 ≤ 120	91.5	79.0	38.6	19.8	10.1	6.5	4.8	2.5	1.3	0.6
	> 120 ≤ 140	70.2	60.6	29.6	15.2	7.8	5.0	3.7	1.9	1.0	0.5
50 Years	≤ 40	177.0	152.9	74.7	38.2	19.6	12.5	9.3	4.8	2.4	1.2
	> 40 ≤ 60	135.4	117.0	57.1	29.2	15.0	9.6	7.1	3.7	1.9	0.9
	> 60 ≤ 80	127.7	110.3	53.9	27.6	14.1	9.0	6.7	3.4	1.8	0.9
	> 60 ≤ 100	104.1	90.0	43.9	22.5	11.5	7.4	5.5	2.8	1.4	0.7
	> 100 ≤ 120	67.9	58.7	28.7	14.7	7.5	4.8	3.6	1.8	0.9	0.5
	> 120 ≤ 140	52.1	45.0	22.0	11.2	5.8	3.7	2.7	1.4	0.7	0.4

[1] Table 7 ratings for PE4710 and PE3608/PE3408 are for free-standing non-pressure pipe with 3% ovality using a safety factor of 2; short-term Poisson ratio, 0.35, used for ½ day load duration; long-term Poisson ratio, 0.45, used for all other load durations. Ratings will vary for greater or lesser ovality, safety factor and load duration. Internal pressure will increase external load resistance by rounding the pipe and counteracting external load. Burial in suitable, properly installed embedment soils can more than triple external load resistance.

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