Guide to Differences in Pressure Rating PE Water Pipe using the ASTM/PPI and ISO Methods
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Foreword

This technical note was developed and published with the technical help and financial support of the members of the PPI (Plastics Pipe Institute, Inc.). The members have shown their interest in quality products by assisting independent standards-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical note is to provide important information available to PPI on describing the differences in the calculated design pressure for water piping applications using the ASTM/PPI and ISO pressure-rating methods. These descriptions are based on discussions with several internationally recognized technical experts in the plastic pipe industry. More detailed information on its purpose and use is provided in the document itself.

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PPI intends to revise this note from time to time, in response to comments and suggestions from users of the note. Please send suggestions for improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting the web site. The initial publication of this note was in 2003 with a first revision in 2013.

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GUIDE TO DIFFERENCES IN PRESSURE RATING PE WATER PIPE BETWEEN THE ASTM/PPI AND ISO METHODS

1.0 Scope and Purpose

This technical note illustrates differences between the North American ASTM/PPI and ISO methods for pressure rating polyethylene (PE) water distribution pipe. This note focuses specifically on pressure rating of PE water pipe because different recommended operating pressures are obtained for the same polyethylene pipe depending on which method is utilized.

This technical note provides general information, background and guidance for comparing ASTM/PPI and ISO-based pressure-rating methods for polyethylene water pipe. It is not an in depth technical comparison of ASTM/PPI and ISO long term stress rating methods. Other documents such as PPI Technical Note 7 (TN-7) and Technical Report 9 (TR-9) and various published technical papers serve this purpose. This note focuses specifically on how the long-term stress ratings determined under the ASTM/PPI and the ISO systems are applied to determine pressure ratings for a polyethylene pressure pipe using these two widely recognized industry protocols.

2.0 Introduction

The North American thermoplastic pipe compound rating methodology uses ASTM standards and PPI policies and procedures to provide design stress ratings that are used to determine polyethylene pipe pressure ratings for various end use applications such as water distribution and transmission. A similar but different rating method, based on ISO standards, is used in other parts of the world.

Potential for confusion exists within the engineering community when these two rating methods are compared because the same polyethylene pipe can appear to have different pressure ratings by one method or the other. Intuitively, the same pipe installed in the same way, operated under the same conditions, would be expected to have the same pressure rating and, hence, the same service lifetime regardless of the rating method used.

In the case of PE water pipe, the pressure rating associated with a specific size and DR can appear to be quite different depending on which standards system is used to rate it. This technical note helps to explain the perceived and real differences between these two rating methods.

3.0 Background

The ASTM/PPI and ISO methods for pressure rating polyethylene water piping developed separately in North America and Europe over nearly half a century. Both methods are technically correct, but when viewed on the surface appear to produce different pressure ratings for the same pipe.

Around 1980, higher strength high density polyethylene materials were introduced in North America and Europe. Under the ASTM/PPI system, these HDPE materials were characterized as PE 3408, and under the ISO system these materials were first characterized as PE 80 and later in 1988 as PE 100 as a result of further improvements in these materials. These nomenclatures for HDPE compounds are similar, but reflect differences in the measurement systems (inch-pound vs. metric) and the stress rating methodologies.

In both nomenclatures, PE is the abbreviation for polyethylene. In PE 3408, the 34 indicates cell classification values for density and slow crack growth in accordance with ASTM D3350, which is a standard for identifying PE piping compounds in North America. The 08 is the material's hydrostatic design stress, HDS, for water at 73°F in hundreds of psi with tens and units dropped; that is 08 = 800 psi. HDS is the material's hydrostatic design basis, HDB, per ASTM D2837 and PPI TR-3 at 73°F multiplied by a design factor, DF for water at 73°F. The HDB is the categorized intercept of the average long term hydrostatic strength at 100,000 hours (11 years). For PE 3408, the ASTM D2837 HDB is 1600 psi and the PPI TR-3 DF is 0.50, which yields a HDS of 800 psi for water at 73°F.

For PE 100, the 100 represents a 10 MPa or 100 bar minimum required strength, MRS, at 20°C in accordance with ISO 9080. MRS is the categorized intercept of the lower predictive limit (LPL) of the material's long term hydrostatic strength at 438,300 hours (50 years) at 20°C (68°F) per ISO 12161.

HDB per ASTM D2837 and MRS per ISO 9080/ISO 12162 are both predicted long- term strength ratings for the PE compound, but are different points at different temperatures and different extrapolated times. The matter is somewhat further complicated as requirements and properties for pressure rated PE compounds may overlap and may be the same or different under the two systems. For example, currently, some PE 4710 compounds can be rated as PE 100 or PE 80 under the ISO protocol, and some PE 100 compounds can be rated as either PE 4710 or PE 3408 when evaluated within the context of the ASTM/PPI protocol. Listings of recommended long-term hydrostatic strengths for PE materials that are rated under the ASTM/PPI and ISO systems are published in PPI TR-4, which is available from www.plasticpipe.org.[1]

[1] Note - As of this writing, commercial factors have resulted in the replacement of PE 3408 compounds by designated as PE 3608 or PE 4710. PE 3408 is used in this discussion because updates to some North American water standards have not yet been completed. Although not reflected in ISO standards, the PE 100 Association identifies PE 100+ as PE 100 with enhanced performance properties.

4.0 The ASTM/PPI Method

The ASTM/PPI pressure rating method was the first of its kind and was initially published in 1962. It uses a categorized long-term hydrostatic strength value, the Hydrostatic Design Basis (HDB), that is reduced by a design factor (DF) to determine an allowable stress (hydrostatic design stress, HDS) for water pipe pressure rating. The HDB is developed by extensive hydrostatic testing of PE pipe samples and mathematical analysis of the stress-rupture data in accordance with ASTM D2837 and the policies of PPI TR-3. The Hydrostatic Stress Board (HSB), an independent assembly of plastics experts within the Plastics Pipe Institute (PPI), reviews data submitted by manufacturers, and then recommends HDB, DF and HDS values for the material to the manufacturer. PPI publishes recommended HDB and HDS values in PPI TR-4, which is available at www.plasticpipe.org. The categorization of HDB values in accordance with ASTM D2837 is replicated here as **Table 1** for ease of reference.

Table 1: Hydrostatic Design Basis Categories per ASTM D2837

Range of Calculated LTHS Values		Hydrostatic Design Basis (HDB)	
psi	**(MPa)**	**psi**	**(MPa)**
190 < 240	(1.31 < 1.65)	200	(1.38)
240 < 300	(1.65 < 2.07)	250	(1.72)
300 < 380	(2.07 < 2.62)	315	(2.17)
380 < 480	(2.62 < 3.31)	400	(2.76)
480 < 600	(3.31 < 4.14)	500	(3.45)
600 < 760	(4.14 < 5.24)	630	(4.34)
760 < 960	(5.24 < 6.62)	800	(5.52)
960 < 1200	(6.62 < 8.27)	1000	(6.89)
1200 < 1530	(8,27 < 10.55)	1250	(8.62)
1530 < 1920	(10.55 < 13.24)	1600	(11.03)
1920 < 2400	13.24 < 16.55)	2000	(13.79)
2400 < 3020	(16.55 < 20.82)	2500	(17.24)
3020 < 3830	(20.82 < 26.41)	3150	(21.72)
3830 < 4800	(26.41 < 33.09)	4000	(27.58)
4800 < 6040	(33.09 < 41.62)	5000	(34.47)
6040 < 6810	(41.62 < 46.92)	6300	(43.41)
6810 < 7920	49.62 < 54.62)	7100	(48.92)
Note: The LTHS is determined to the nearest 10 psi. Rounding procedures in Practice E29 should be followed.			

HSB recommended design factors for water service are based on an engineering risk assessment for two groups of variables; testing quality and application requirements. The first HSB design factor, 0.50, was developed in the early 1960's as part of the ASTM/PPI rating method and has historically been uniformly applied to all thermoplastic pipe materials covered in PPI TR-3. It is generally accepted that the HSB recommended 0.5 design factor takes into consideration the following:

- Resin variation
- Test data accuracy
- Pipe extrusion and processing variables

- Handling during storage, shipping and installation
- Typical static loads relating to installation
- Typical dynamic loads, surges and water hammer
- Uncertainty relating to system operation

Interest in PE 100 and their apparently higher water piping pressure ratings under the ISO system initiated activity in the PPI and ASTM standards areas to determine if the allowable stress for North American PE water piping could be increased without increasing the risk of premature service failure. In this effort, both rating systems and PE material properties were carefully examined and compared.

In 2001, the HSB undertook a detailed investigation of ASTM/PPI and ISO rating methods to determine if certain higher performing polyethylene materials could be reliably operated at higher stress. The results of this investigation were published in 2005 in PPI TR-3 Sections D.7 and F.7. These sections are excerpted below.

D.7 ESTABLISHING THE HYDROSTATIC DESIGN STRESS FOR A MATERIAL

D.7.1 The hydrostatic design stress (HDS) at 73°F (23°C) is derived by multiplying the HDB of the material by a design factor (DF). The Hydrostatic Stress Board will recommend a design factor for each material which has a HDB listed in TR-4.

D.7.2 The recommended design factor shall not exceed 0.50, unless material-specific policies and requirements are developed and are included in the appropriate Part(s) of TR-3. The HDS calculated using this design factor will be used in establishing the thermoplastic pipe material designation code.

D.7.3 Policies and requirements specific to polyethylene are listed under Part F.7 of TR-3.

D.7.4 Policies and requirements specific to other materials will be added to TR-3 as they are considered and developed by the HSB.

F.7 REQUIREMENTS FOR POLYETHYLENE (PE) MATERIALS TO QUALIFY FOR A HIGHER DESIGN FACTOR

A PE material that meets the following requirements qualifies for a recommended design factor of 0.63. PE materials not meeting these requirements will have their HDS established as per Part D.7.

1. 50 year substantiation according to Part F.5.

2. Minimum slow crack growth performance by ASTM F 1473 of 500 hours as required by ASTM D 3350.

3. LCL/LTHS ratio of at least 90% as per ASTM D 2837.

These requirements apply to the PE material – meaning that all compounding ingredients and colorants are included matching the material formulation to be listed. The HDS calculated with this design factor will be used to establish the pipe material designation code to be listed in TR-4.

The Hydrostatic Stress Board of the PPI, determined that a design factor of 0.63 could be utilized to pressure-rate PE pipe based on the significantly higher performance capabilities of specific polyethylene pipe compounds, particularly as it relates to advancements in polymer technology that improved long-term ductility and toughness leading to increased resistance to slow crack growth (SCG) and rapid crack propagation (RCP). As a result of this, we see that different design factors are now applied to specific material designations as shown in Table 2 below.

Table 2: ASTM/PPI Design Factors for PE Pipe in Water Service

ASTM Material Designation Code	Hydrostatic Design Basis per ASTM D2837, psi	ASTM/PPI Design Factor for Water	ASTM/PPI Hydrostatic Design Stress, psi
PE 1404	800	0.50	400
PE 2406	1250	0.50	625
PE 3408	1600	0.50	800
PE 3708	1600	0.50	800
PE 4708	1600	0.50	800
PE 2708*	1600	0.63	800
PE 3710*	1600	0.63	1000
PE 4710*	1600	0.63	1000

*Denotes high performance PE compound in accordance with PPI, TR-3

Within the ASTM/PPI method, Equation 1 below is used to calculate the pressure rating for a PE water pipe for service at 73°F. The design factor employed is either 0.50 or 0.63 in accordance with PPI TR-3 Sections D.7 and F.7.

$$P = \frac{2 \times HDB \times DF}{(DR - 1)} = \frac{2 \times HDS}{(DR - 1)} \qquad \text{Eq. (1)}$$

Where:
- P = Pressure rating for water at 73°F (23°C) in psi
- HDB = Hydrostatic design basis, psi
- DR = Dimension ratio
  = average outside diameter (in) / minimum wall thickness (in)
- DF = Design Factor
  = 0.50 or 0.63

Example: 73°F water pressure rating calculations for DR 11 pipe produced from PE materials having a design factor established as 0.50 or 0.63 in accordance with TR-3 Section D.7 are as follows:

$$PE3408: \quad P = \frac{2 \times 1600 \times 0.50}{(11-1)} = \frac{2 \times 800}{10} = 160\,psi \approx 11 bar$$

$$PE4710: \quad P = \frac{2 \times 1600 \times 0.63}{(11-1)} = \frac{2 \times 1000}{10} = 200\,psi \approx 14 bar$$

From this, we see that PE 3408 DR 11 water pipe has a pressure rating of 160 psi (11 bar) within the ASTM/PPI method, and that PE 4710 DR 11 pipe has a pressure rating of 200 psi (14 bar) for water service at 73ºF. The difference is that PE 3408 must use the HSB recommended 0.50 DF in accordance with Section D.7 where PE 4710 qualifies for the HSB recommended 0.63 DF by meeting the additional performance requirements of PPI TR-3 Section F.7.

For temperatures other than 73°F (23° C), PPI TR-9 recommends the use of a temperature design factor or the use of an HDB established at a higher temperature. PPI publishes HDB values in TR-4 at 73°F and also at other selected elevated temperatures (120°F, 140°F, etc). Where recommended by the manufacturer, the HDB at this elevated temperature is used with the appropriate service design factor and without the need for a temperature design factor.

$$HDS_{(140°F)} = [HDB_{(140°F)}] \times DF \qquad \text{Eq. (2)}$$

Where:
- $HDS_{(140°F)}$ = Hydrostatic design stress at 140°F
- $HDB_{(140°F)}$ = Hydrostatic design basis at 140°F
- DF = Design factor = 0.50 or 0.63

5.0 The ISO Method

The ISO pressure rating method is similar to the ASTM/PPI method. It also uses a categorized long-term strength value called the Minimum Required Strength (MRS) that is divided by a design coefficient, *C,* to develop a design stress, σ_s, that is used to determine pipe pressure rating. MRS is a long-term hydrostatic strength rating for the PE material that is determined through mathematical analysis of long-term PE pipe tests in accordance with ISO 9080 and then categorization in accordance with ISO 12162. The difference between MRS within the ISO system and HDB within the ASTM/PPI system is that the MRS rating point is the lower predictive limit of the 20°C (68°F) long term hydrostatic strength at 438,300 hours (50 years), whereas the HDB is the mean of the 73°F (23°C) long term hydrostatic strength at 100,000 hours (11 years).

Manufacturers may also submit MRS data to the Hydrostatic Stress Board for review and recommendation of MRS for the compound. HSB recommended

MRS values are published in PPI TR-4, which is available at www.plasticpipe.org. MRS values are in MPa rather than psi. The HSB does not recommend *C* values for use with MRS or the resultant design stress, σ_S. Recommended minimum values for *C* are designated within ISO 12161.

The categorization of MRS values in accordance with ISO 12162 is replicated here as Table 3 for ease of reference. It should be noted here that the table values shown are in MPa as opposed to Imperial units (psi).

Table 3: MRS Classifications per ISO 12162

Range of lower confidence limits σ_{LPL} MPa	Minimum Required Strength MRS MPa	Classification Number [a]
$1 \le \sigma_{LPL} < 1,25$	1	10
$1,25 \le \sigma_{LPL} < 1,6$	1,25	12.5
$1,6 \le \sigma_{LPL} < 2$	1.6	16
$2 \le \sigma_{LPL} < 2,5$	2	20
$2,5 \le \sigma_{LPL} < 3.15$	2,5	25
$3,15 \le \sigma_{LPL} < 4$	3.15	31.5
$4 \le \sigma_{LPL} < 5$	4	40
$5 \le \sigma_{LPL} < 6,3$	5	50
$6,3 \le \sigma_{LPL} < 8$	6.3	63
$8 \le \sigma_{LPL} < 10$	8	80
$10 \le \sigma_{LPL} < 11,2$	10	100
$11,2 \le \sigma_{LPL} < 12,5$	11,2	112
$12,5 \le \sigma_{LPL} < 14$	12,5	125
$14 \le \sigma_{LPL} < 16$	14	140
$16 \le \sigma_{LPL} < 18$	16	160
$18 \le \sigma_{LPL} < 20$	18	180
$20 \le \sigma_{LPL} < 22,4$	20	200
$22,4 \le \sigma_{LPL} < 25$	22,4	224
$25 \le \sigma_{LPL} < 28$	25	250
$28 \le \sigma_{LPL} < 31,5$	28	280
$31,5 \le \sigma_{LPL} < 35,5$	31,5	315
$35,5 \le \sigma_{LPL} < 40$	35,5	355
$40 \le \sigma_{LPL} < 45$	40	400
$45 \le \sigma_{LPL} < 50$	45	450
$50 \le \sigma_{LPL} < 56$	50	500

[a] If the classification number is not an integer, a full stop is used instead of a comma

ISO 12162 designates minimum service design coefficients, C, for water applications at 20ºC (68°F) for various thermoplastic materials. For PE, C is 1.25. It should be noted that C is applied as a divisor where DF is applied as a multiplier. ISO 12162 further specifies that higher design coefficients may be chosen in the case of

a) Specific requirements for the products such as additional stresses and other effects which are considered to occur in the application;

b) Influence of temperature and time (if different from 20°C, 50 years) and/or influence of environment;

c) Standards that are based on MRS, where other temperatures of operation are required.

A comparison of DF and *C* shows that *C* generally does not consider the following attributes.

- Handling during storage, shipping and installation
- Typical static loads relating to installation
- Typical dynamic loads, surges and water hammer
- Uncertainty relating to system operation

Under the ISO system, the designer should address these factors and increase C as appropriate for the specific application.

As in the ASTM/PPI method, MRS is reduced by C to obtain a design stress, σs that is used to determine a maximum pressure rating for water at 20°C. This relationship is shown in Eq. 3.

$$P = \frac{20}{(DR-1)}\frac{MRS}{C} = \frac{20}{(DR-1)}\sigma_S \qquad \text{Eq. (3)}$$

Where:

P	=	Maximum pressure rating for water at 20°C (68° F) in bar
MRS	=	Minimum Required Strength in MPa
σ_s	=	design stress in MPa
DR	=	Dimension ratio
	=	minimum outside diameter (mm) / minimum wall thickness (mm)
C	=	Design Coefficient
	≥	1.25

An example calculation for PE 100 DR 11 pipe for water at 20°C (68°F) is:

$$P = \frac{20}{(11-1)}\frac{10}{1.25} = \frac{20}{(10)}8 = 16\,bar \approx 230\,psi$$

This is the maximum pressure rating for PE 100 water piping at 20ºC (68°F) using the ISO recommended minimum design coefficient, C, of 1.25.

***<u>Note:</u>* The ISO method divides the design stress by a design coefficient (≥ 1) to derate the pipe as opposed to multiplying the design stress by a design factor (≤1) as is done in the ASTM/PPI method. The net effect is the same, to reduce the maximum design stress of the pipe. Other ISO application product standards may apply higher or**

additional design coefficients to further reduce the design pressure based on other application specific variables.

Note: ***A significant difference is that this ISO recommended design coefficient only takes into consideration the variations due to extrusion and processing and static water pressure. When using the ISO method, it is the responsibility of the design engineer or governing authority to determine the actual application conditions and apply additional design coefficients required for the specific application.***

As defined in ISO 12162, the MRS is the categorized value of the LPL (lower predictive level) at 20ºC (68°F) and 50 years. For any other temperature or any other time, ISO 12162 defines the categorized value of that LPL as the CRS (categorized required strength). This is the methodology used by the ISO system to account for the effect of temperature or the effect of time on the LPL value. The pressure rating at the desired temperature or desired time is obtained by using the Equation 2 as above, except that the CRS value is substituted for the MRS value. This methodology is very accurate as it uses the same 90 data points for ISO 9080 to calculate the CRS that were used to calculate the MRS.

To account for different temperatures, one could also use temperature design factors as an alternative to using the CRS. However, just as using the elevated temperature HDB is more accurate than a temperature design factor within the ASTM/PPI methodology, using the CRS is considered more accurate than a temperature design factor within the ISO methodology.

6.0 Conclusions

The above discussion and examples illustrate the differences between ASTM/PPI and ISO pressure-rating methodologies. This difference in pressure rating is attributed, in large measure, to the ASTM/PPI method's more conservative design factor that provides for normally anticipated pipe manufacturing, handling and installation, and operation factors. The design coefficient used in the ISO method accounts only for normally anticipated pipe manufacturing factors. In the ISO method the design engineer is responsible for ascertaining additional handling and installation, and operation factors and increasing the 1.25 design coefficient for the application. ISO 12162 provides some guidance in the application of additional design coefficients.

Additional differences in the two methods relate to the determination of long-term strength by HDB or MRS. Both methods apply various assumptions, requirements, temperature basis and mathematical treatment of the data to arrive at a different categorized long-term strength forecast. These inherent differences will result in a different design basis. For more information on the differences in the long-term stress rating methods under ASTM/PPI and ISO, the reader is referred to PPI's TN-7.

In practice, the ISO methodology reflects maximum pressure ratings and the designer should address reduction factors for the application that are not in the minimum 1.25 design coefficient. For the ASTM/PPI methodology used in North America additional pressure reduction factors would generally only be considered for extremely severe applications.

At this point, a DR 11 ASTM/PPI PE 4710 pipe is rated for 200 psig (14 bar) water service at 73°F/23°C, but a DR 11 PE 100 pipe under the ISO system is rated for 230 psig (16 bar) for water service at 20°C/68°F. The appearance is that the same DR water pipe at about the same service temperature has a 15% difference in allowable service pressure as PE 4710 or PE 100, but the actual difference is that the rating methods set different allowable design stress and are at different temperatures. The performance potential of a single PE piping material is still the same whether it is designated a PE4710 or PE100. However, the pressure-rating methods under the two systems are different. Both are valid when used within the context of each respective system. Taking one element of one system and combining it with elements of the other system may lead to erroneous results.

In conclusion, this document provides some guidance in comparing the two rating methods for PE pipes in water applications, and why each may appear to result a slightly different maximum pressure rating. It is ultimately the responsibility of the system designer to determine the operating and service conditions for a particular water system and how to address those needs using either of these pressure rating systems.

References:

PPI TN-7, *"The Nature of Hydrostatic Stress Rupture Curves",* Plastics Pipe Institute, Irving, TX, 2005.

PPI TR-9, *"Recommended Design Factors and Design Coefficients for Thermoplastic Pressure Pipe",* Plastics Pipe Institute, Irving, TX, 2002

PPI TN-41, *"High Performance PE Materials for Water Piping Applications"*, Plastics Pipe Institute, Irving, TX, 2007

ASTM D2837, *"Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products*", ASTM International, West Conshohocken, 2011.

PPI TR-3, *"Policies and Procedure 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",* Plastics Pipe Institute , Irving, TX, 2012

ISO 9080, *"Plastics Piping and Ducting Systems-Determination of the Long-Term Hydrostatic Strength of Thermoplastics Materials in Pipe Form by Extrapolation",* International Organization for Standardization (ISO), Geneva, Switzerland, 2012

ISO 12162, *"Thermoplastics Materials for Pipes and Fittings for Pressure Applications-Classification, Designation and Design Coefficient",* International Organization for Standardization (ISO), Geneva, Switzerland, 2009

Appendix I

Commonly Accepted Conversion Factors

1 MPa = 145 psi (stress)
1 bar = 14.5 psig (pressure)