

**Recommended Design
Factors and Design
Coefficients for
Thermoplastic Pressure Pipe**

TR-9

2025



Foreword

RECOMMENDED DESIGN FACTORS AND DESIGN COEFFICIENTS FOR THERMOPLASTIC PRESSURE PIPE

This report was developed and published with the technical help of the members of the Hydrostatic Stress Board (HSB) and PPI (Plastics Pipe Institute, Inc.) members. 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 technical reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

The purpose of this technical report is to provide important information available to PPI on recommended design factors and design coefficients for thermoplastic pressure piping applications. These recommendations are based on discussions with internationally recognized technical experts in the plastic pipe industry. More detailed information on its purpose and use is provided in the document itself.

This report has been prepared by PPI as a service to the industry. The information in this report is offered in good faith and believed to be accurate at the time of its preparation but is offered “as is” without any express or implied warranty, including **WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE**. Additional information may be needed in some areas, especially with regard to unusual or special applications. Consult the manufacturer or material supplier for more detailed information. PPI does not endorse the proprietary products or processes of any manufacturer and assumes no responsibility for compliance with applicable laws and regulations.

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RECOMMENDED DESIGN FACTORS AND DESIGN COEFFICIENTS FOR THERMOPLASTIC PRESSURE PIPE

1.0 INTRODUCTION

This Technical Report provides a summary of recommended design factors used with the Hydrostatic Design Basis (HDB) determined in accordance with ASTM D2837 and PPI TR-3, recommended design coefficients (C) used with the Minimum Required Strength (MRS) determined in accordance with ISO 9080 and ISO 12162, and calculated design stress values for pipes produced from HDB and MRS stress rated thermoplastic compounds.

A design factor applied to an HDB and a design coefficient applied to an MRS differ due to the conventions and assumptions by which the HDB and the MRS values are determined. Therefore, design factors applied to HDB rated compounds and design coefficients applied to MRS rated compounds, are used only with the respective rating system and cannot be interchanged. However, it is the position of PPI that when pipes are made from the same compound for the same application and with the same installation practices operated at the same stress levels and same temperatures, the pipes will perform the same regardless of the stress-rating method, e.g., ASTM (HDB) or ISO (MRS), used to evaluate the strength of the material for that application.

Other PPI Technical Reports that are concerned with pressure applications of thermoplastic pipe compounds are *PPI TR-2 PPI PVC Range Composition Listing of Qualified Ingredients*, *PPI TR-3, "Policies and Procedures for Developing HDB, PDB, SDB and MRS Ratings for Thermoplastic Piping Materials or Pipe"*, and *PPI TR-4, "PPI Listing of HDB, SDB, PDB, MRS Ratings for Thermoplastic Piping Materials or Pipe"* and *HSB-R01 - The Nature of the 0.63 Design Factor (DF) for Qualified Polyethylene Pipe Compounds*.

These recommended design factors and design coefficients have been developed on the basis of decades of North American and international field experience, engineering tests, investigations, and safety considerations. Experience to date indicates that the recommended design factors in this report are conservative within the limits for which they are recommended. However, guarantee or warranty is not assumed regarding their application and use. Under some conditions, other than which the hydrostatic testing was conducted, such as cyclic pressure applications, chemically aggressive fluids, and the like, or applications where the consequences of failure are heightened, additional design factors and design coefficients must be considered by the design engineer (see Sections 5.3, 5.4, 5.5 and 6.3).

2.0 REFERENCES

All references are specific to the most recent version available, unless otherwise indicated.

2.1 PPI Documents

TR-2 PPI PVC Range Composition Listing of Qualified Ingredients

TR-3 HDB/HDS/PDB/SDB/MRS Policies – Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stresses (HDS), Pressure Design Basis (PDB), Strength Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

TR-4 HDB/HDS/SDB/PDB/MRS Listed Materials – PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe

HSB-R01 - The Nature of the 0.63 Design Factor (DF) for Qualified Polyethylene Pipe Compounds

2.2 ASTM Standards

ASTM D1598 Standard Test Method for Time-to-Failure of Plastic Pipe Under Constant Internal Pressure

ASTM D2837 Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products

ASTM F412 Standard Terminology Relating to Plastic Piping Systems

2.3 ANSI Standards

ANSI-Z17.1 Numbers, Preferred

2.4 ISO Standards

ISO 3 Preferred numbers – Series of preferred numbers¹

ISO 161-1:1996 Thermoplastic pipes for the conveyance of fluids – Nominal outside diameters and nominal pressures

ISO 497 Guide to the choice of series of preferred numbers and of series containing more rounded values of preferred numbers²

ISO 3213 Polypropylene (PP) pipes — Effect of time and temperature on the expected strength

ISO 4437 Plastics piping systems for the supply of gaseous fuels - Polyethylene (PE)

ISO 9080 Plastics piping and ducting systems -- Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation

ISO 10508 Plastics piping systems for hot and cold water installations — Guidance for classification and design

ISO/TS 10839 Polyethylene pipes and fittings for the supply of gaseous fuels — Code of practice for design, handling and installation

ISO 12162 Thermoplastics materials for pipes and fittings for pressure applications -
- Classification, designation and design coefficient

ISO 13760 Plastics pipes for the conveyance of fluids under pressure — Miner's rule — Calculation method for cumulative damage

ISO 15494 Plastics piping systems for industrial applications — Polybutene (PB), polyethylene (PE), polyethylene of raised temperature resistance (PERT), crosslinked polyethylene (PE-X), polypropylene (PP) — Metric series for specifications for components and the system

ISO 16422 Pipes and joints made of oriented unplasticized poly(vinyl chloride) (PVC-O) for the conveyance of water under pressure — Specifications

ISO 16486 Plastics piping systems for the supply of gaseous fuels - Unplasticized polyamide (PA-U) piping systems with fusion jointing and mechanical jointing

¹ R10 series of preferred numbers

² R20 series of preferred numbers

3.0 TERMINOLOGY

Similar terminology is used in the HDB and the MRS based methodologies. To avoid confusion, the reader is cautioned to review the terminology presented in the specific context of use with each methodology. Further, the equations shown in this terminology section are explained later in the document.

3.1 Hydrostatic Design Basis (HDB) Method

Related terms are grouped to assist understanding of the differences between the definitions.

Dimension Ratio (DR) – the average outside diameter of the pipe divided by the minimum wall thickness. The DR values are rounded to the nearest 0.5 unless otherwise specified [ref: ASTM F412]. When the DR conforms to the R10 preferred number series plus one, the term Standard Dimension Ratio (SDR) is applied [ASTM F412].

Standard Dimension Ratio (SDR) – a specific ratio of the average specified outside diameter to the minimum specified wall thickness (D_o/t) for outside diameter-controlled plastic pipe, the value of which is derived by adding one to the pertinent number selected from the ANSI Preferred Number Series 10 [ASTM F412].

Standard Inside Dimension Ratio (SIDR) – a specific ratio of the average specified inside diameter to the minimum specified wall thickness (D_i/t) for inside diameter controlled plastic pipe, the value of which is derived by subtracting one from the pertinent number selected from the ANSI Preferred Number Series 10 [ref: ASTM F412].

Hydrostatic Design Basis (HDB) psi – one of a series of established stress values specified in the long-term strength-based methodology D2837 and is obtained by categorizing the LTHS determined in accordance with D2837 for a plastic pipe compound at a specified temperature [ref: ASTM F412].

Note 1: The Hydrostatic Stress Board (HSB) recommended HDB values at 73°F and elevated temperatures for sustained water pressures are listed in PPI TR-4.

Note 2: LTHS increments up to 1250 psi HDB are based on the R10 series. For LTHS values above 1250 psi HDB, the increments are based on the R20 series [ref: ASTM D2837; ANSI Standard Z17.1 for Preferred Number].

Hydrostatic Design Stress (HDS), psi – the estimated maximum tensile stress (psi) in the wall of the pipe in the circumferential orientation due to internal hydrostatic pressure that can be continuously applied with a high degree of certainty that failure of the pipe will not occur [ref: ASTM F412].

Note 3: The HSB recommended HDS values for sustained water pressures at 73°F are listed in PPI TR-4.

$$\mathbf{HDS = HDB \times DF_{HDB}} \quad \text{Eq (1)}$$

where:

HDS = hydrostatic design stress, psi

HDB = hydrostatic design basis as per ASTM D2837, psi

DF_{HDB} = design factor for sustained water pressure at 73°F.

Reference: DF_{HDB} is defined in Section 3.2 HDB Method: Factor

Long-Term Hydrostatic Strength (LTHS), psi – an estimated tensile stress in the wall of the pipe in the circumferential orientation that when applied continuously, will cause failure of the pipe at 100,000-hours. This is the intercept of the stress regression line with the 100,000-hours coordinate [ref: ASTM D2837].

Long-Term Hydrostatic Pressure Strength (LTHS_p), psi – the estimated internal pressure that when applied continuously will cause failure of the pipe at 100,000-hours. This is the intercept of the pressure regression line with the 100,000-hours intercept [ref: ASTM D2837].

Pressure Design Basis (PDB), psig – one of a series of established pressure values for a plastic piping component (multilayer pipe, fitting, valve) obtained by categorizing the long-term hydrostatic pressure strength (LTHS_p) determined in accordance with an industry test method that uses linear regression analysis [ref: ASTM F412].

Pressure Rating (PR), psi – the estimated maximum pressure (psig) that the fluid in the pipe can exert continuously with a high degree of certainty that failure of the pipe will not occur [ref: ASTM D2837].

$$\mathbf{PR = \frac{2 \times (HDB \times DF_{HDB})}{(DR-1)} = \frac{2 \times HDS}{(DR-1)}} \quad \text{Eq (2)}$$

Note 4: When needed, include in the numerator service factors (e.g., environmental, chemical or temperature) to calculate the pressure rating.

3.2 HDB Method: Factors

Related terms are grouped to assist understanding of the differences between the definitions.

Hydrostatic Design Basis Factor (DF_{HDB}) - a dimensionless number less than 1.00 used to reduce the HDB into an engineering design stress taking into consideration the variables and margin of safety involved in a properly installed thermoplastic pressure pipe. The HSB recommended DF_{HDB} are for sustained water pressure at 73°F.

Note 5: In past PPI publications, the design factor was referred to as “DF”. The term was renamed to DF_{HDB} to clarify that this factor differs from others used in the industry today such as service design factors, temperature design factors, and chemical design factors.

Note 6: Reference PPI TR-3 Notes to the Reader No. 3 and No. 4 for additional guidance applying design factors above 73°F and when consideration of environmental factors is needed.

Service Design Factor (F_s) – a dimensionless number less than 1.00 applied to the HDB that takes into account additional pipeline operating conditions, and/or provides an additional margin of safety due to greater risk or consequence of failure.

Note 7: Service Design Factors are sometimes referred to as Service Factors.

Service Temperature Factor (F_T): a dimensionless number less than 1.00 applied to the HDB when the service temperature differs from the one used to establish the LTHS and when interpolation of the LTHS is not possible.

Service Chemical Factor (F_c): a dimensionless number less than 1.00 applied to the HDB when effects from an internal media or an external environmental condition exist (e.g., exposure to certain chemicals).

Note 8: For potable water systems using chlorine as the disinfectant, refer to PPI TN-43³ for the classification of the polyethylene compound, PPI TN-44⁴ to determine the long-term resistance of the HDPE pipe, PPI TN-49 for AWWA C901 service tubes⁵ or refer to PEX ASTM standards for the classification of the PEX tubing or PEX pipe.

Note 9: PPI PE Handbook 2nd Ed, Chapter 6 provides additional guidance on service chemical factors which are sometimes referred to as Environmental Application Factors (A_F).

³ PPI TN-43 PE Compound Categorization for Potable Water Applications”, 2020.

⁴ PPI TN-44 Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants”, 2015.

⁵ PPI TN-49 Recommendations for AWWA C901 Service Tubes in Potable Water Applications

3.3 Minimum Required Strength (MRS) and Categorized Required Strength (CRS) Methods

Related terms are grouped to assist understanding of the differences between the definitions.

Categorized Required Strength ($CRS_{\theta,t}$), MPa - a categorized value of the lower prediction limit (σ_{LPL}) of the ISO 9080 long-term strength at temperature (θ) and at time (t) [ref: ISO 12162]. $CRS_{\theta,t}$ is also used in Equations 3 in place of MRS.

Extrapolation time factor (k_e), dimensionless – factor for calculation of the extrapolation time [ref: ISO 9080].

Extrapolation times (t_e), hrs – time limit for which extrapolation is allowed [ref: ISO 9080].

Note 10: The extrapolation time of the stress regression line, is beyond actual test conditions.

Long-Term Hydrostatic Strength (σ_{LTHS}), MPa– when analyzed in accordance with ISO 9080, the σ_{LTHS} is the predicted mean strength, hoop stress, that when applied continuously, will cause failure of the pipe at a specified temperature and time. This is the intercept of the 20°C stress regression line with the 438,000 hours (50 years) coordinates as analyzed in accordance with ISO 9080 [ref: ISO 9080, ISO 12162].

Lower Prediction Limit (σ_{LPL}), MPa – the 97.5% lower confidence level of the predicted hydrostatic strength at a temperature and time [ref: ISO 9080].

Minimum Required Strength (MRS), MPa - a categorized lower prediction limit (σ_{LPL}) of the ISO 9080 long-term strength at 20°C and 50-years. [ref: ISO 12162].

Note 11: When categorizing the σ_{LPL} to the MRS or CRS, the value is rounded down to the next smaller value of R10 series when less than 10 MPa or in the R20 series when greater or equal to 10 MPa. The R10 series is based on ISO 3 and the R20 series is based on ISO 497 [ref: ISO 12162].

Maximum Allowable Operating Pressure (P_{PMS}), MPa – an estimated sustained pressure that can be exerted with a high degree of certainty that failure of the pipe will not occur at 20°C [ref: ISO 161-1:1996].

$$P_{PMS} = \frac{2 \times MRS}{C_{min} \times (SDR - 1)} \quad \text{Eq (3)}$$

Nominal Pressure (PN)– a dimensionless numerical designation used for reference purposes related to the mechanical characteristics of the component of a piping system [ref: ISO 161-1:1996].

Note 12: For plastic piping systems conveying water, the PN number corresponds to the maximum continuous operating pressure, expressed in bar, which can be sustained with water at 20°C, based on the minimum design coefficient [ref: ISO 4427-1:2007].

Maximum Allowable Design Stress (σ_s), MPa:

- **When based on the MRS classification (σ_s), MPa** – MRS divided by the minimum design coefficient determines the maximum allowable design stress that can be continuously applied with a high degree of certainty that failure of the pipe will not occur [ref: ISO 12162].

$$\sigma_s = \frac{\text{MRS}}{C_{\min}} \quad \text{Eq (4)}$$

- **When based on the $\text{CRS}_{\theta,t}$ classification ($\text{CRS}_{\theta,t}$), MPa** – The $\text{CRS}_{\theta,t}$ divided by the minimum design coefficient determines the maximum allowable design stress, at temperatures and times other than 20°C and 50 years, that can be continuously applied with a high degree of certainty that failure of the pipe will not occur. [ref: ISO 12162].

$$\sigma_{\theta,t} = \frac{\text{CRS}_{\theta,t}}{C_{\min}} \quad \text{Eq (5)}$$

3.4 MRS Methods: Coefficients and Factors

Related terms are grouped to assist understanding of the differences between the definitions.

Design Coefficient (C), dimensionless – coefficient with a value greater than 1, which takes into consideration service conditions as well as properties of the components of a piping system other than those represented in the lower confidence limit [ref: ISO 12162]. When the design coefficient is noted as C_{\min} , it is the minimum value that is used to calculate the maximum value of the MRS or $\text{CRS}_{\theta,t}$ [ref: ISO 12162].

It is used in the denominator of the ISO pressure equation, Eq (13).

Derating Coefficient or also known as a Derating Factor (D_F) – a number used to reduce the maximum operating pressure due to the influence of temperature [ref: ISO TS 10839 Annex A]. It is applied by multiplying against the design coefficient (C) in the denominator of the pressure equation, Eq (13).

Note 13 – ISO 10839 is a polyethylene application standard for the supply of gaseous fuels. The mention is only provided as an example. The reader is encouraged to review the product standards for the respective applications as the term and values can vary.

4.0 SIGNIFICANCE OF DESIGN FACTOR (DF) AND DESIGN COEFFICIENT (C)

The term “design factor” and “design coefficients” are conceptual in that they consider numerous manufacturing and testing variables involved, the degree of reliability selected and the resulting failure mechanisms of the pipe compound as well as the possibility of other pipe or pipeline service condition effects.

Although there are many types of design factors and design coefficients accounting for different variables, they all have the same function, to reduce the strength basis of the pipe system to a design stress. Consequently, the concepts contribute to the safe operation of the pipe system over its service life.

Establishing a design factor or design coefficient, for a pipe or pipeline service can be challenging, as there are many variables to consider. The significance of, or weighting of, those variables depend on the application and situation. The approach taken with plastic pipe systems is to use design factors or design coefficients to reduce the material’s long-term strength that has been established under a standard set of conditions. Additional factors (e.g., service, chemical, etc.) are then applied to address the effects of conditions that could potentially affect the long-term performance of the pipe system or to apply a different level of conservatism to the design.

Another concept of importance, is that design factors and design coefficients are not the same as safety factors although the terms are often used interchangeably⁶. Design factors and design coefficients account for multiple variables and reduce the long-term strength design basis to a design stress - the sustained stress the pipe can withstand with a high degree of certainty that the failure of the pipe or pipeline will not occur [see Section 3.1]. The design factors and design coefficient in the following discussions take into account variations such as testing, manufacture, dimensions and the assumptions in the evaluation procedures themselves used to determine the material’s long-term strength, as well as the impact of typical installation conditions. Due to the viscoelastic response of most thermoplastics, the ductile failure line shows a negative slope when plotted as log stress vs log time to fail. Due to the conservatism of the strength basis methodologies (e.g., HDB, MRS, PDB, CRS) where the categorization occurs after 10⁵ or more hours, the actual hoop stress capability for resisting short-term burst, stress intensification failures, cyclic fatigue, etc. will be much greater than the hoop stress calculated from the DF as applied to the HDB or C as applied to the MRS, may imply.

Note 14: Reference the design coefficient definition for an explanation of conditions that it accounts for.

In regard to the ASTM methodology, stress reduction factors (design factors) are intended to take into account two general groups of conditions. Group 1 considers manufacturing and testing variables; specifically, normal variations in the material, manufacture, dimensions, and in the evaluation procedures (for example ASTM D2837, ASTM D1598) [ref; ASTM D2837 Section 5.5]. The HSB publishes recommended design factors (DF_{HDB}), for material designations within their policies, which typically reflect the conditions in this first group (Group 1). Historically, the design factors applied by the HSB

⁶ Technical Report, Design and Safety Factors for PE4710 Materials Under the Proposed Revision to AWWA C906: March 2011, Jana Laboratories

considered Group 1 and parts of Group 2 ^{7,8}. Applying the DF_{HDB} , is the first reduction of the HDB to the engineering hydrostatic design stress (HDS) specifically for sustained water pressure at 73°F which is the baseline temperature for recommended HDBs listed in PPI TR-4.

Group 2 considers the application or use, specifically installation, environment, temperature, hazard involved, life expectancy desired, and the degree of reliability selected [ref; ASTM D2837 Section 5.5]. The service design factor (F_s) is selected so that the hydrostatic design stress obtained provides a service life for an indefinite period beyond the actual test period [ref: ASTM D2837]. Service design factors for this second group of conditions are governed by the industry standards or by code agencies and/or by the design engineer.

5.0 THE HYDROSTATIC DESIGN BASIS (HDB) APPROACH

5.1 HDB and HDS

The Hydrostatic Design Basis (HDB) is the categorized LTHS determined in accordance with ASTM D2837. General thermoplastic piping product standards or code authorities use the recommended HDB and HDS at 73°F and HDB at elevated temperatures for sustained water pressure to establish maximum operating pressures. Examples of the standards organization or code authorities include but are not limited to such as ASTM, or governmental agencies or code authorities such as United States Department of Transportation (DOT) or American Society of Mechanical Engineers (ASME). The HSB lists recommended HDB and maximum recommended HDS values for specific thermoplastic piping compounds in PPI TR-4. The listed HDB values have been developed in accordance with the requirements of ASTM D2837 and the policies of PPI TR-3. The design factor (DF_{HDB}) is used to obtain these recommended HDS values from the HDB values. A common design factor used in the pressure pipe industry is 0.50. PPI TR-3 also details policies that stipulate additional performance requirements for polyethylene compounds to qualify for a higher design factor⁹. The HDS is calculated as shown previously in Eq (1):

$$\mathbf{HDS = HDB \times DF_{HDB}} \qquad \mathbf{Eq (1)}$$

where:

HDS = hydrostatic design stress, psi

HDB = hydrostatic design basis as per ASTM D2837, psi

DF_{HDB} = design factor for sustained water pressure at 73°F.

⁷ The Hydrostatic Stress Board of Plastics Pipe Institute: The First 50 Years, Journal of ASTM International, Vol. 8, No. 4, S. Mruk

⁸ HSB-R01-The Nature of the 0.63 Design Factor (DF) for Qualified Polyethylene Pipe Compounds

⁹ See PPI TR-3 Part F.7, Requirements for Polyethylene (PE) and PPI HSB-R01 Technical Report detailing the development of the PE 0.63 DF.

5.2 Recommended Hydrostatic Design Basis Factors (DF_{HDB})

Some of the industry accepted maximum DF_{HDB} are given in Table 1. It is best to review the standards and/or regulations specific to the application before selecting a design factor.

Table 1 –HSB Recommended DF_{HDB} for Sustained Water Pressure at 73°F for use with HDB Rated Compounds listed in PPI TR-4

Pipe Material Designation Codes	DF_{HDB}	Pipe Material Designation Codes	DF_{HDB}
PVC1120	0.5	PEX0006	0.5
PVC2116	0.5	PEX1006	0.5
CPVC4120	0.5	PEX3006	0.5
CPVC4122	0.5	PEX3206	0.5
PE1404	0.5	PEX3306	0.5
PE2406	0.5	PEX5006	0.5
PE2708	0.63	PEX5106	0.5
PE3408	0.5	PEX5206	0.5
PE3608	0.5	PEX5306	0.5
PE3708	0.5	PEX0008	0.5
PE3710	0.63	PEX1008	0.5
PE4608	0.5	PEX3008	0.5
PE4708	0.5	PA32312	0.5
PE4710	0.63	PA32316	0.5
PVDF2016	0.5	PA42316	0.5
PVDF2020	0.5		
PVDF2025	0.5		

5.3 Service Design Factor (F_s)

Codes for specific applications, regulations, or jurisdictions may require a more conservative approach reflecting additional design or safety considerations and thereby apply a service design factor (F_s). A governmental agency or code writing authority may reference the recommendations published in PPI TR-4 or prescribe the service design factor. As an example, the United States national pipeline safety regulations, Title 49 CFR, Part 192 mandates a maximum service design factor of 0.4 for plastic pipe made from PE, PA-11 and PA-12 compounds used in regulated natural gas distribution applications¹⁰. Also, service conditions may require use of a chemical factor (F_c) as well (see Section 5.5).

$$\mathbf{HDS = HDB \times F_s} \qquad \text{Eq (6)}$$

where:

HDS = hydrostatic design stress for the specified service, psi

HDB = hydrostatic design basis for sustained water pressure at 73°F

F_s = service design factor specified by the governmental agency or code writing authority

Note 15: The CFR Code 192 uses the term “design factor”. With the plastic pipe rule announced in 2020, the code allows the use of a service design factor of 0.4 for PE2708, PE3710 and PE4710 compounds. The calculation is $0.4 = 0.63 \times F_c \times F_T$, where $F_c = 0.8$ and $F_T = 0.8$ ^{10,11}.

Note 16: The previous 0.32 F_s applied by Department of Transportation 49 CFR 192 comprises conservatism for temperature and chemical: $0.32 = 0.5 \times F_c \times F_T$ where $F_c = 0.8$ and $F_T = 0.8$ ¹¹. The “...additional 0.8 multiplier covers long term effects from constituents in fuel gas, and another 0.8 multiplier compensates for use at increased temperatures above 73°F”¹¹.

5.4 Service Temperature Factor (F_T)

5.4.1 Using recommended HDB established at an elevated temperature

HSB publishes recommended HDB values in PPI TR-4 for sustained water pressure at 73°F and at other standard elevated temperatures such as 140°F, 180°F and 200°F. Where recommended by the manufacturer, the HDB at this elevated temperature is used with the appropriate DF to determine the HDS at the elevated temperature. This is the simplest approach in determining the HDS at the elevated temperature. However, the design factor applied at the elevated temperature (DF) might be even more conservative compared to the DF_{HDB} . The equation is the same form as Eq (1) but the HDB is the one established at the elevated temperature. The subscript letter “H” is only used in this document as an aid and is not used in the industry.

¹⁰ Federal Register/ Vol. 83, No. 224/ Tuesday, November 20, 2018/ Rules and Regulations, page 58717

¹¹ Federal Register/ Vol. 83, No. 224/ Tuesday, November 20, 2018/ Rules and Regulations, page 58697

$$\mathbf{HDS_H = HDB_H \times DF} \quad \text{Eq (7)}$$

where:

HDS_H = hydrostatic design stress at the elevated temperature, psi

HDB_H = hydrostatic design basis at PPI TR-4 listed elevated temperature, psi

DF = design factor applied to the HDB.

**The DF applied to HDB_H should consider the effects of the elevated temperatures.

Reference: Note 6 of this document provides additional guidance.

5.4.2 Using the Interpolation Equation based on HDB

For PPI TR-4 listed materials that have an established recommended HDB at two temperatures, it is possible to interpolate the HDB for a temperature (T_I) between those points, such as a service temperature. Before using this procedure, confirm the relevant product standards and codes do not exclude this approach. The interpolation equation to calculate the Service Temperature Factor (F) is in accordance with PPI *Handbook of Polyethylene, Second Edition, Chapter 3*.

$$\mathbf{F_T = 1 - \left[\frac{(HDB_L - HDB_H)}{HDB_L} \times \frac{\left(\frac{1}{T_L} - \frac{1}{T_I}\right)}{\left(\frac{1}{T_L} - \frac{1}{T_H}\right)} \right]} \quad \text{Eq (8)}$$

where:

F_T = factor at an intermediate temperature

HDB_L = hydrostatic design basis at the lower temperature (psi)

HDB_H = hydrostatic design basis at an elevated temperature (psi)

T_L = low temperature, °R

T_I = intermediate temperature, °R

T_H = elevated temperature, °R

Note 17: The PPI PE Handbook of Polyethylene Pipe, 2nd Ed, refers to F as the Temperature Compensating Multiplier.

Note 18: The baseline temperature in PPI TR-4 is 73°F for sustained water pressure

And then, by applying the intermediate temperature factor to obtain the HDS_I

$$\mathbf{HDS_I = HDB_L \times DF_{HDB} \times F_T} \quad \text{Eq (9)}$$

where:

HDS_I = hydrostatic design stress at an intermediate temperature (psi)

Note 19: HDS values listed in PPI TR-4 are at 73°F.

Interpolation requires HDB's at a low and an elevated temperature. Where PPI TR-4 does not list HDB's at two temperatures, interpolation to determine a factor for an elevated intermediate temperature is not possible, and the user should contact the manufacturer for an appropriate factor at the desired temperature (e.g., F_T). Also, if the temperature exceeds the established elevated temperature HDB for a material, or is below the HDB at base temperature, the manufacturer should be consulted to obtain an appropriate factor at the desired temperature.

5.4.3 Using the Interpolation Equation based on LTHS

PPI TR-3 Part D.2 Interpolation policy is based on the actual experimental LTHS determined in accordance with ASTM D2837 and PPI TR-3. If one or both of the LTHS values are unknown, then this policy is not applicable. This is a realistic scenario as most times, the specific LTHS value is only known to those who own the compound formulation.

This interpolation concept is the same as that presented in Section 5.4.2, in that, values at two established endpoints are used to determine the intermediate value. From a mathematical perspective, the two approaches are the same. However, from the perspective of the values used, the HDB and LTHS differ significantly. The HDB is a range of LTHS values for each category whereas the LTHS is a very discrete experimentally determined point that is then categorized in accordance with ASTM D2837.

Section 5.4.2, Eq (8) is based on the HDB and therefore, it is not necessary to categorize HDB once calculated. However, when PPI TR-3 Part D.2 policy is applied, the interpolated LTHS (S_T) must be categorized in accordance with ASTM D2837 to determine the HDB at the intermediate temperature.

$$S_T = S_L - \left[\frac{(S_L - S_H) \times \left(\frac{1}{T_L} - \frac{1}{T_T} \right)}{\left(\frac{1}{T_L} - \frac{1}{T_H} \right)} \right] \quad \text{Eq (10)}$$

where:

- S_T = LTHS at the interpolation temperature, psi
- S_L = LTHS at the low temperature, psi
- S_H = LTHS at the elevated temperature, psi
- T_L = low temperature, °R
- T_T = interpolation temperature, °R
- T_H = elevated temperature, °R

Note 20: The compound manufacturers know the experimentally determined LTHS values. As such, the PPI TR-3 Interpolation Policy is typically used by them.

5.5 Service Chemical Factors (F_c)

Due to wide differences in chemical resistance of various thermoplastic piping materials, specific attention should be given to possible chemical effects of the transported fluid or of external environment chemical effects on the pipe compound. Experience has shown that the effects of air, ground or rain water, and alkaline or acidic soils as well as internally transported elements such as potable water (see Note 21), natural gas, and neutral salt (brine) solutions have little or no effect on the long-term stress rating of most thermoplastic pressure piping materials.

Note 21: PPI TN-43 *PE Compound Categorization for Potable Water Applications*, PPI TN-44 *Long Term Resistance of AWWA C906 Polyethylene (PE) Pipe to Potable Water Disinfectants* and PPI TN-49 *Recommendations for AWWA C901 Service Tubes in Potable Water Applications* provide additional guidance for polyethylene pressure pipe used in potable water applications.

Note 22: For polyamides, the hydrostatic testing used to determine the long-term strength is typically conducted on water-saturated pipe specimens. In this way, the effect of water on polyamides is accounted for.

However, other fluids and some solvents or liquid hydrocarbons that may be present as contaminants in embedment soils may have a significant effect on the material's long-term strength that the user must take into account. In these cases, the use of a service chemical factor, F_c , is appropriate.

With liquid hydrocarbons and other chemicals, temperature can have a disproportional effect on the long-term performance of the pipe. It is not possible to establish a general service chemical factor for elevated temperature service and as such, each case should be designed on its own merit. Likewise, applied stress can also affect whether or not a chemical may have an effect. PPI TR-19¹² and TR-22¹³ provide chemical resistance guidance for various thermoplastics. In addition, Note 6 of this document can be referenced.

¹² PPI TR-19 Chemical Resistance of Thermoplastics Piping Materials, 2021.

¹³ PPI TR-22 Polyethylene Piping Distribution Systems for Components of Liquid Petroleum Gases, 2013

5.6 Pressure Rating (PR)

Multiple design factors (service, temperature, chemical, others) may be necessary for certain applications and are used to obtain the appropriate engineering design stress for the application or conditions. Pressure rating is specific for the conditions of an application and varies when the conditions are changed. A pipe may have a pressure rating for one application but have a higher or lower pressure rating for different conditions in the same application. For thermoplastic pressure pipe, the conditions usually having a significant effect on pressure rating are service temperature, the fluid being transported, chemical effects, and/or codes and regulations.

The user is cautioned that pressure ratings published in literature are usually for a standard application such as the pressure transport of water at standard base temperature of 73°F in a benign chemical and external load environment. Where a user application varies from standard application conditions, a lower pressure rating can apply and must be taken into account when selecting a thermoplastic piping product for an application.

For a given application, the pressure rating (PR) is calculated from equation Eq (2), shown below when using the dimension ratio (DR) for outside diameter (OD) controlled pipe. For comparison, the calculation using the standard inside dimension ratio (SIDR) for inside diameter (ID) controlled pipe is shown as Eq (11):

$$PR = \frac{2 \times (HDB \times DF_{HDB})}{(DR - 1)} = \frac{2 \times HDS}{(DR - 1)} \quad \text{Eq (2)}$$

$$PR = \frac{2 \times (HDB \times DF_{HDB})}{(SIDR + 1)} = \frac{2 \times HDS}{(SIDR + 1)} \quad \text{Eq (11)}$$

where:

- PR = pressure rating using either the OD or ID, psig (MPa)
- HDB = hydrostatic design basis at a specified temperature, psi (MPa)
- DF_{HDB} = design factor applied to the HDB
- HDS = hydrostatic design stress at a specified temperature, psi (MPa)
- DR = dimension ratio (for OD controlled pipe)
- SIDR = standard inside dimension ratio (for ID controlled pipe)

5.7 Pressure Design Basis (PDB)

This PDB methodology is used for complex structures such as composite and certain types of polymeric multilayer pipes. The PDB is determined by categorizing the long-term hydrostatic pressure strength ($LTHS_p$) in accordance with ASTM D2837. The HSB publishes recommended Pressure Design Basis (PDB) values in PPI TR-4 at 73°F (23°C) and elevated temperatures for sustained water pressure.

$$PR = PDB \times DF_{PDB} \quad \text{Eq (12)}$$

where:

- PR = pressure rating, psig
- PDB = pressure design basis at a specified temperature, psi
- DF_{PDB} = design factor applied to the PDB value, typically 0.5 for PDB listed structures

6.0 THE MINIMUM REQUIRED STRENGTH (MRS) AND THE CATEGORIZED REQUIRED STRENGTH (CRS) APPROACH

To assure understanding in this context, review applicable Terminology.

6.1 Minimum Required Strength (MRS)

The Minimum Required Strength (MRS) is the categorized value of the σ_{LPL} at 20°C and 50 years as determined in accordance with ISO 9080 and ISO 12162, rounded down to the next smaller value of the R10 or R20 series. The MRS is multiplied by 10 to determine the classification number (e.g., PE100, PE80, PE-X80, PE-X100, etc.). PPI TR-4 lists recommended MRS ratings for thermoplastic piping materials. ISO 12162 also provides established minimum design coefficients, C_{min} , for various thermoplastic compounds to determine the maximum allowable engineering design stress.

Note 23: The classification, minimum design coefficient and calculation method are based on the resistance to internal pressure with water at 20°C for 50 years, derived by extrapolation using the method given in ISO 9080 [ref: ISO 12162].

The MRS classifications and minimum design coefficient values in ISO 12162 do not qualify a material for a specific application. For specific applications, the relevant ISO product standards have additional mechanical, physical property and reference line requirements that must be met.

The maximum allowable design stress is obtained by dividing the MRS by the minimum design coefficient, C_{\min} [ref: ISO 12162 Clause 3.6.1]. The relevant ISO product standards specify the required design stress for the different applications.

$$\sigma_s = \frac{\text{MRS}}{C_{\min}} \quad \text{Eq (4)}$$

where:

MRS	= minimum required strength at 20°C and 50-years, MPa
C_{\min}	= minimum design coefficient
σ_s	= maximum allowable design stress, MPa

6.2 Categorized Required Strength ($\text{CRS}_{\theta,t}$)

The CRS is the categorized value of the σ_{LPL} at temperature θ and time t that is determined in accordance with ISO 9080 and ISO 12162, rounded down to the next smaller value in the R10 or R20 series, and is not at the specific conditions of 20°C and/or 50-years. This allows design engineers to select the temperature (θ , in Celsius) and design time (t , in years) that reflects the system. Use Eq (5) to calculate the $\sigma_{(\theta,t)}$ at a time or temperature other than 20°C or 50-years.

The maximum time is limited to 100-years and the temperature is not less than 20°C below the lowest test temperature [ref: ISO 12162 Annex A]. The extrapolation time factors (k_e) in ISO 9080 used to calculate the extrapolation times (t_e) shall be respected. It is important to check the relevant ISO product standards to confirm this approach is applicable. There are materials used in hot and cold-water applications, such as PP, CPVC, PEX, PE-RT and others, that use reference lines to confirm the performance when needed [ref: ISO 12162 Clause 5]. ISO 12162 and PPI TR-3 detail policies on obtaining a $\text{CRS}_{\theta,t}$ recommendation for listing in PPI TR-4.

Note 24: ISO reference lines are created in accordance with technical specification, ISO TS 26873. Standards such as ISO 15494 and ISO 3213 detail reference lines for many thermoplastic materials.

Note 25: ISO standards for hot and cold-water plastic pipe systems use application classes where each are specific to a set of design conditions [ref: ISO 10508].

6.3 Design Coefficient (C)

ISO 12162 describes a design coefficient, C , that is specified in the relevant product standards, and provides values for minimum design coefficients, C_{\min} , for thermoplastic piping materials at 20°C as shown in Table 2.

ISO 12162 recommends higher (more conservative) design coefficients where there are:

- “specific requirements for the products such as additional stresses and other effects which are considered to occur in the application;”

- “influences of temperature and time (if different from 20°C, 50-years) and/or an influence of environment;”
- “standards that are based on MRS, where other temperatures of operation are required.”

Table 2 - ISO 12162 Values of C_{min}

Thermoplastic	C_{min}
ABS	1,6
PB	1,25
PE	1,25
PE-X	1,25
PP copolymer	1,25
PP homopolymer	1,6
PVC-C	1,6
PVC-HI	1,4
PVC-U	1,6
PVC-O (for MRS ≤ 40)	1,6 ^a
PVC-O (for MRS > 40)	1,4 ^a
PVDF copolymer	1,4
PVDF homopolymer	1,6
PA11	1,6
PA12	1,6
PPSU	1,4

^a In accordance with Table 1 of ISO 16422

Note 26: For the ISO standards, commas are used for decimals.

The minimum design coefficient, C_{min} , is related to the specific thermoplastic material. The design coefficient, C , for a given application is specified in relevant ISO product standards and considers service conditions as well as properties of the components of a piping system other than those represented in the lower confidence limit [ref: ISO 12162].

National code, regulations or relevant product standards may require a more conservative engineering design stress than is obtained using C_{min} per ISO 12162 or C per the applicable ISO product standard. Such examples include liquid petroleum gas (LPG) applications where ISO 4437 requires a C factor that is 10% greater than that of natural gas [ref: ISO 4437-1:2014]. For PA-11 and PA-12, the design coefficient for supply of gaseous fuels is a minimum of 2 or higher [ref: ISO 16486]. Another example is detailed in the code of practice for gas applications, ISO TS 10839 where derating coefficients (D_F) are applied to account for the influence of operating temperatures as shown in Eq (13). Interpolation for an intermediate temperature is possible using the values given in ISO TS 10839 Annex A.

$$MOP = \frac{20 \times MRS}{C \times (SDR-1) \times D_F} \quad \text{Eq (13)}$$

where:

C	=	design coefficient
MRS	=	minimum required strength at 20°C and 50 years, MPa
D_F	=	derating coefficient per ISO TS 10839
MOP	=	maximum operating pressure, MPa
SDR	=	standard dimension ratio (for OD controlled pipe)

It is noted that for gas applications, when using a derating factor of 0.90 at 10°C, the design coefficient C should not be less than 2 when calculated from the equation [ref: ISO TS 10839]. When the temperature is 40°C, the derating factor is 1.3 [ref: ISO TS 10839]

6.4 Nominal Pressure (PN) and Pressure Rating (p_{PMS})

ISO 161-1:1996 provides two designations related to the pressure capacity of thermoplastic piping, nominal pressure, PN, and maximum allowable pressure rating, p_{PMS} .

6.4.1 Nominal Pressure (PN)

Nominal Pressure (PN), is a dimensionless reference number per ISO 161-1:1996. This number is used for identifying pipes having comparable pressure capacity at 20°C for sustained water pressure conditions. The PN is equal to the maximum allowable operating pressure (p_{PMS}) when the unit of bar is used at 20°C [ref: ISO 161-1:1996].

6.4.2 Maximum Allowable Operating Pressure Rating (p_{PMS})

The maximum allowable operating pressure (p_{PMS}) is for the pipe specified in the product standard, or for an application. When conditions are temperatures other than 20°C or fluids are those other than water, the maximum allowable operating pressure is calculated as follows [ref: ISO 161-1:1996]:

$$p_{PMS} = \frac{2 \times \sigma_s}{C \times (SDR - 1)} \quad \text{Eq (14)}$$

where:

p_{PMS}	=	maximum allowable operating pressure, MPa
σ_s	=	engineering design stress, MPa
C	=	overall service design coefficient
SDR	=	standard dimension ratio (for OD controlled pipe)]

6.5 Addressing Pressures and/or Temperatures that are not constant

ISO Methodology applies Miner's Rule in calculating the maximum allowable hoop stress for pipes subject to varying pressures and/or temperatures over their lifetime and is only applied to one failure mechanism at a time [ref: ISO 13760]. In summary of the concept, the total exposure to varying conditions is cumulative over the course of one year where the total permissible time of exposure, is then compared to the time the system is required to operate. If the permissible time is not equal or greater than the required, the operating stress is adjusted. Before applying Miner's Rule, it is important to understand the specifics of the four assumptions. ISO 13760 details the procedure and assumptions to make when applying Miner's Rule.

7.0 EVALUATIONS USING ASTM AND ISO METHODOLOGIES

HDB and MRS methodologies differ due to their respective requirements and assumptions in ASTM D2837 and ISO (9080 and 12162) for predicting material performance under constant stress and constant temperature. Thermoplastic materials can be, and frequently are, evaluated under both methodologies. While the ratings obtained may differ, this does not reflect differences in the long-term strength of the compound, but rather the specifics of each rating system. Some compounds have achieved both an HDB and an MRS classification when evaluated in accordance with ASTM D2837 and ISO 9080/ ISO 12162 respectively^{14,15}. The long-term strength methodology does not change actual performance of the compound.

8.0 CONCLUSION

This PPI Technical Report provides information on use of design factors with HDB rated thermoplastic materials, the use of design coefficients with MRS rated thermoplastic materials, and information for deriving pipe pressure ratings under the respective systems. Due to differences in HDB and MRS rating systems, design factors applied to HDB rated materials and design coefficients applied to MRS rated materials, are used only with the respective rating system and cannot be interchanged.

¹⁴Keller, D. 2016. Comparative Testing of Pre-Pigmented and Natural Compound Plus Black Coloring Master Batch HDPE Pipes for Potable Water Applications, ANTEC paper P484, Bethel, Connecticut: Society of Plastics Engineers

¹⁵ PPI TR-4 HDB/HDS/SDB/PDB/MRS Listed Materials – PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe