HISTORICAL REVIEW OF PRESSURE RATING METHODS FOR PE AND PEX PIPE IN GAS APPLICATIONS

PPI TR-55

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Plastics Pipe Institute
The Voice of an Industry.

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Foreword

This technical report 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 report is to provide important information available to PPI on a particular aspect of polyethylene and PEX piping systems for various pressure applications. This report has been prepared by PPI as a service of the industry. The information in this note 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. Any reference to or testing of a particular proprietary product should not be construed as an endorsement by PPI, which does not endorse the proprietary products or processes of any manufacturer. The information in this report is offered for consideration by industry members in fulfilling their own compliance responsibilities. PPI assumes no responsibility for compliance with applicable laws and regulations.

PPI intends to revise this model specification within 5 years or sooner if required, from the date of its publication, in response to comments and suggestions from users of the document. Please send suggestions for improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting our website.

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1.0 SCOPE

This Technical Report (TR) describes key features of the two pressure rating methods for plastic piping compounds used in gas pressure piping applications:

1. ASTM D2837, the North American pressure rating method, called the HDB (hydrostatic design basis), first published in 1969, and
2. ISO 9080 and ISO 12162, the international pressure rating method, called the MRS (minimum required strength), first introduced in the 1970's.

This technical report first discusses the differences in the pressure ratings determined by these two methods for gas distribution and gas gathering applications. This technical report then reviews changes made to the design factors during the past few years to several industry standards, such as ASTM, CSA, and API. This technical report is not an endorsement for either of these two pressure-rating methods for gas applications. **PPI does not recommend one method or the other – both are technically sound methods used by the industry. This technical report simply provides a historical overview and current status of these two pressure-rating methods.**

It is important to keep in mind that when calculating a design pressure (P) for a particular plastic pipe made from a certain material, this design pressure is dependent on the particular application that the pipe is used for and also dependent on regional or national codes and regulations for selecting the design factor. As stated in PPI TN-28, recommended design factors are based on an engineering risk assessment that incorporates two groups of variables; testing quality and application requirements. The design pressure for a PE or PEX pipe is calculated for a given application and pipe material with consideration to the risk. The design factor (DF) used with the HDB in the ASTM equation is generally regulated for certain jurisdictions with consideration for various risks. Gas engineers select the design factor within the confines of the regulations governing their jurisdiction. The resulting design pressure considers those risks calculated within the minimum safety standards of local regulations. The design pressure in ISO using the MRS equation calculates, with the minimum design coefficient (C), the maximum design pressure allowed. Local regulations may specify a lower design pressure. Gas engineers select the appropriate design coefficient for their application. Using these two design equations, the design pressure for a given pipe may be different using HDB and DF (under certain jurisdictions) than when calculated with MRS and C "for the same pipe". When reviewing this Technical Report, the reader must keep in mind that one jurisdiction can view risk differently than another jurisdiction for a given application.

2.0 PRESSURE RATING METHODS

PPI TN-28 “Guide to Differences in Pressure Rating PE Water Pipe between the ASTM and ISO Methods” and PPI TR-9 “Recommended Design Factors for Pressure Applications of Thermoplastic Pipe Materials” provide a comparison of the ASTM **(HDB)** and the ISO **(MRS)** pressure rating methods. Below are the two equations discussed in PPI TN-28 for determining the **pressure rating (P)** for a given **standard dimension ratio (SDR)** of the pipe.

ASTM HDB

$$P = [2 \times HDB \times DF] / (DR - 1) \quad \text{Equation 1}$$

Where:

P = Pressure rating, psig
HDB = Hydrostatic Design Basis, psi
DF = Design Factor, dimensionless
DR = Dimension Ratio, dimensionless

ISO MRS

$$P = 20 \times MRS / [(DR - 1) \times C] \quad \text{Equation 2}$$

Where:

P = Pressure rating, bar
MRS = Minimum Required Strength, MPa
DR = Dimension Ration, dimensionless
C = Design Coefficient, dimensionless

It is important to note the differences in the conditions for each design basis.

- The listed HDB is established by extrapolation to 100,000 hours at individual temperatures where baseline is 73°F (23°C). Additionally, the listed hydrostatic design stress (HDS), which is the HDB times the design factor (DF), is specific to the condition of 73°F (23°C) for an unspecified time frame for design life, generally accepted to be in excess of 100 years.
- In regard to the MRS, which uses a design coefficient (C) instead of a design factor, the conditions are specific to 20°C and 50 years. ISO 12162 and the respective effect of time - temperature standards provide guidance on selecting and applying temperature factors or use of reference lines or the Categorized Required Strength (CRS) for conditions other than 20°C or 50-years.

2.1. ASTM D2837

The ASTM D2837 methodology is applicable to thermoplastic compounds in the form of a pipe. The methodology applies to both pipe manufacturing processes: inline compound and precompounded grades. The pressure rating equation utilizes the pipe dimensions (SDR), the HDB determined in accordance with ASTM D2837, and the selected design factor (DF).

In regard to the design factor, the ASTM methodology details two groups of conditions that the design factor is generally based on. These conditions reflect the upstream (e.g., compounds, testing, manufacturing, etc.) and downstream (e.g., installation, use, application, etc.) aspects of a plastic pipe system[1]. Additionally, D2837 does not provide service design factors but defers selection to the design engineer. Overall, the intent is the selection of a design factor resulting in an engineering design stress (hydrostatic design stress) which "provides a service life for an indefinite period beyond the actual test period."[1]

Within the industry, the Plastics Pipe Institute Hydrostatic Stress Board (PPI HSB) has recommended design factors for thermoplastic pressure pipe compounds since 1962[2]. The historical design factor has been 0.5 DF for all thermoplastic compounds until ~2005 when the 0.63 DF was introduced for higher performance polyethylene pressure pipe compounds. This recommendation is irrespective of service condition other than a temperature basis of 73°F. Both recommendations have served the plastics pipe industry well for many decades.

For this technical report, the discussion focuses on the application design factor, which is sometimes called the service design factor. Other factors, such as chemical design factor and temperature design factor, also need to be considered by the system design engineer but are outside the scope of this technical report.

2.2. ISO 9080 / ISO 12162

The ISO methodology was developed by ISO TC138 WG5 TG10 and it was in 1976 when this group of experts first met[3]. After use within the industry, the first edition officially published as ISO/Technical Report 9080 in 1992, and this TR became an official ISO Standard several years later. ISO 12162, the classifications for the ISO methodology, is recorded to have first published in 1995. The ISO 9080 / ISO 12162 methodology is applicable to thermoplastic compounds in the form of a pipe made by either pipe manufacturing process,

[1] ASTM D2837 Standard Test Method for Obtaining Hydrostatic design Basis for Thermoplastic Pipe

[2] The Nature of the 0.63 Design Factor (DF) for Qualified Polyethylene Pipe Compounds HSB-R-01/2015

[3] ISO/TR 9080:1992 Thermoplastics pipes for the transport of fluids – Methods of extrapolation of hydrostatic stress rupture data to determine the long-term hydrostatic strength of thermoplastics pipe materials.

precompounded resin, or in-line blended resin. Some ISO application standards require precompounded pipe.

The ISO methodology utilizes design coefficients (C) that are generally mandated by the application product standard. The ISO design coefficient considers service conditions and the properties of the plastic pipe system components[4]. ISO 12162 provides minimum design coefficients at 20°C which are specific to each thermoplastic material. These minimum design coefficients result in the maximum pressure rating as the value (C) is utilized in the denominator of the ISO pressure equation. Some product standards such as ISO 14531 utilize the minimum design coefficient[5]. Others utilize higher design coefficients which result in a lower pressure rating. One example of the latter is the supply of gaseous fuels standard for polyethylene, which requires a 2.0 design coefficient (C) for gaseous fuel transportation and a 2.2 minimum C for LPG[6].

While ISO 9080/12162 and ASTM D2837 methods can, in theory, be applied to PE pipe of any sort, practically it should be understood that these methods exist as part of two distinct pressure rating systems—systems which also include differing product requirements (i.e.: ISO 4437 and ASTM D2513).

3.0 HISTORICAL REVIEW

3.1. PE 100 History

Polyethylene (PE) has been the compound of choice for the regulated and non-regulated gas industry both domestically and internationally since around 1970[7, 8]. In the mid-1980's high-performance PE 100 compounds were introduced in Europe[9]. These PE 100 compounds have a unique combination of higher stress ratings (MRS), outstanding resistance to slow crack growth (SCG), along with outstanding resistance to rapid crack propagation (RCP).

[4] ISO 12162:2009 Thermoplastics materials for pipes and fittings for pressure applications – Classification, designation and design coefficient.
[5] ISO 14531-1 Plastics pipes and fittings – Crosslinked polyethylene (PE-X) pipe systems for the conveyance of gaseous fuels – Metric series – Specification Part 1: Pipes
[6] ISO 4437 also specifies an acceptable maximum design stress of 4.0 MPa and 5.0 MPa at a reference temperature of 20°C
[7] H. Van Speybroeck. The use of PE pipes in the Gas Industry Up to 10 Bar. 18th World Gas Conference, Berlin, 1991.
[8] G. Palermo. High Performance Bimodal PE 100 Materials for Gas Piping Applications. AGA Conference, 2005.
[9] U. Schulte. A Vision Becomes True – 50 Years of Pipes Made From High Density Polyethylene. PPXIII. Washington D.C. 2006.

In regard to the pipe manufacturing process, the application standards set the requirements for the pipe manufacturing process. For example:

- ISO 4437, the product standard for PE gas pipe, requires use of a precompounded grade for the manufacture of the pipe. ISO 9080 does not require a precompounded grade for PE 100 classification.
- In CSA B137.4 for PE gas pipe, the PE 100 pipe can be made from an inline compounded grade (e.g., blend of natural resin and an approved masterbatch option designated by the resin supplier) or precompounded.
- For PE 100 compounds listed in PPI TR-4, the method of pipe manufacture is not specified. All PE100 compounds listed in TR-4 conform to ISO 9080 and ISO 12162.

Because of the many advantages of high-performance PE 100 compounds, European PE resin manufacturers began to introduce PE 100 compounds into North America in the mid 1990's[10]. Since the ISO methodology was not recognized in the ASTM standards, these PE 100 compounds were classified as PE3408 in the ASTM HDB system. As shown in Section 4.1, the gas distribution engineer determined the pressure rating using the ASTM HDB methodology. This resulted in a lower pressure rating for the regulated SDR 11 PE 3408 pipe based on the HDB method compared to the regulated SDR 11 PE 100 pipe pressure rating based on the MRS method. In some cases, the same PE compound was listed as both a PE3408 compound and a PE 100 compound in PPI TR-4. Section 4.2 provides the comparison for non-regulated gas gathering applications.

3.2. <u>Design Factors Recommended by the PPI HSB</u>

The Plastics Pipe Institute Hydrostatic Stress Board (PPI HSB) utilized a design factor of 0.5 for all solid wall thermoplastic compounds listed in PPI TR-4 used in a water application. In 2005, HSB introduced requirements in PPI TR-3 for a 0.63 design factor for high performance PE materials. Gas distribution applications use a different design factor. This design factor is not a service design factor but rather, a factor to reduce the hydrostatic design basis (HDB) to an engineering hydrostatic design stress (HDS). In the early 2000s, the PPI HSB formed an HDB/ MRS Task Group to investigate the performance criteria and differences in pressure ratings between the ASTM and ISO systems[2]. Based on the findings of an extensive study investigating the technological advancement of PE pressure pipe compounds and the differences between the ASTM and ISO systems, the PPI HSB increased the design factor from 0.5 to 0.63 for high performance PE compounds meeting the requirements of PPI TR-3 Part F.7. This study is detailed in the PPI HSB white paper: *HSB-R01/2015*[2].

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[10] B. Berndtson, Classification Systems and How to Utilize Material Performance. Thirteenth Plastic Fuel Gas Pipe Symposium, 1993.

Technical Report HSB-R01/2015 provides important information regarding actions and recommendations taken by the PPI HSB in qualifying polyethylene pressure pipe compounds for the application of a 0.63 DF. The information includes the final decision of the PPI HSB, a summary and discussion of the research undertaken that resulted in the 0.63 design factor recommendation, a brief history on the origin of the 0.50 design factor and how the 0.63 design factor relates to it.

The introduction of the 0.63 DF resulted in a new hydrostatic design stress (HDS) at 73°F for PE pressure pipe compounds meeting the requirements of PPI TR-3 Part F.7. To account for the changes, the industry introduced new pipe material designation codes to reflect the technological advancements of the modern PE pressure pipe grades. Industry discussions and the revisions to ASTM D3350 took about 10 years to complete. The key change reflected the significantly improved slow crack growth resistance without lowering the density of the compound. These were represented by the classification of ‘4’ and ‘7’, respectively. A more detailed account and historical summary of the PE pipe material designation codes are recorded in a PPI document in the process of being published - TN 68 “Historical Review of the PE 100-RC Concept – How PE4710 Compares to PE 100-RC”.

The PE high density compounds qualifying for a higher design factor still had the same hydrostatic design basis (HDB) of 1600-psi at 73°F. However, by utilizing the 0.63 DF, the HDS at 73°F calculated to a 1000-psi instead of the 800-psi when applying the 0.5 DF. The pipe material designation code was then PE4710. For a 1250-psi HDB at 73°F medium density, calculated to an 800-psi HDS at 73°F instead of a 630-psi HDS when utilizing a 0.63 DF. The pipe material designation code was then PE2708.

Compounds listed with the PPI HSB were tested using a specific set of conditions: sustained water pressure at a constant temperature and constant test stress in accordance with ASTM D1598 or ISO 1167. This set of test conditions is the ideal case. An engineer can then modify the engineering design stress determined for the ideal case by utilizing additional factors or a service design factor, in order to design a system for the intended application.

4.0 COMPARISON OF ASTM AND ISO DESIGN EQUATIONS

4.1. Pressure Rating Differences for Regulated Gas Distribution Systems

The Pipeline and Hazardous Materials Safety Administration (PHMSA) regulates gas distribution applications in the United States of America (USA). The gas operator must use the design equation specified in the Department of Transportation (DOT) Code of Federal Regulations (CFR) Part 192.121 which is the same design equation in PPI TN-28 (Equation 1 in this technical report). Part 192.121 specifies the service design factor to use for regulated gas distribution applications. This service design factor applies equally to all class locations for all population densities, i.e. Class I, II, III, and IV.

4.1.1. ASTM Pressure Rating Utilizing a 73°F HDB

When PE 100 was first introduced in North America in the 1990’s, the ISO MRS design equation was not recognized. Using the ASTM HDB Equation 1, the ASTM pressure rating for an SDR 11 PE3408 pipe and utilizing a service design factor of 0.32, as stipulated by DOT for a gas distribution application in the mid 1990’s, is shown below[11]. This pressure rating was the **maximum** pressure that a gas design engineer could operate their PE3408 pipeline at 73°F.

$$P = [2\ (1600)\ (0.32)\ /\ (11-1)] = 102 \text{ psig.}$$

The ASTM pressure rating for gas distribution applications, based on the DOT Part 192.121 design factor of 0.32 for all class locations, was 102 psig for an SDR 11 PE3408 pipe.

In 2018, PHMSA communicated the change in the design factor for all class locations used for gas distribution in Part 192.121 from 0.32 to 0.40 for the higher performance PE2708 and PE4710 compounds[11]. Using Equation 1 for an SDR 11 PE4710 pipe, the calculated pressure rating increased from 102 psig to 128 psig (limited to 125 psig by Federal Code).

4.1.2. ISO Pressure Rating Utilizing an MRS (20°C, 50-years)

Using Equation 2, the ISO pressure rating for an SDR 11 PE 100 pipe utilizing the minimum design coefficient of 2.0 recommended by ISO 4437 for gas distribution applications is shown below[12], [13]. This is the **maximum** pressure rating that a gas design engineer could operate their PE 100 pipeline at 20°C. The gas engineer has the option to increase the design coefficient, for an added measure of safety, which would result in a **lower** pressure rating.

$$P = [20\ (10)\ /\ (11-1)\ (2.0)] = 10 \text{ bar} = 145 \text{ psig.}$$

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

[12] ISO 4437 also specifies an acceptable maximum design stress of 4.0 MPa and 5.0 MPa at a reference temperature of 20°C.

[13] European countries, utilizing ISO standards, might have or not have a regulatory body. Further, each country could have their own national specifications for the different applications. For this technical report, the design coefficient stated in the ISO standards will be utilized for the comparison of the design pressures between the two systems.

The ISO maximum pressure rating for gas distribution applications, utilizing the ISO 4437 minimum design coefficient of 2.0, is 10 bar or 145 psig for an SDR 11 PE 100 pipe. This is why PE 100 is often called the "10 bar resin".

4.1.3. Comparison of the Pressure Ratings[14, 15]

This difference in pressure ratings between PE 100 (145 psig) and PE3408 (102 psig) resulted in the PPI HSB forming an HDB/ MRS Task Group to investigate the material performance criteria and differences between the ASTM and ISO systems. This Task Group recommended increasing the maximum recommended design factor from 0.5 to 0.63 for certain high performance PE compounds that met additional stringent performance criteria.

For regulated gas distribution applications, the AGA Plastic Materials Committee (PMC) and the Operations Technology Development (OTD) group desired to use a similar increase in operating stress by revising the federally mandated regulated gas design factor from 0.32 to 0.40 resulting in a petition to PHMSA. The pressure rating for some PE3408 compounds with a 0.32 DF was increased from 102 psig to 128 psig when it was classified as a PE4710 pipe with a 0.4 DF. At the time of this writing, within the ISO methodology, the PE 100 pipe pressure ratings are only 13% higher than the PE4710 pipe design pressure rating for the same gas distribution pipe under the minimum safety standards of the U.S. Code of Federal Regulations for the transportation of gas. In current days, many PE 100 compounds hold dual listings as both a PE 100 and a PE4710 compound.

Cautionary Note: It is important to keep in mind that when calculating a design pressure (P) for a particular plastic pipe made from a certain material, this design pressure is dependent on the particular application that the pipe is used for and is also dependent on regional or national codes and regulations for selecting the design factor. As stated in PPI TN-28, recommended design factors are based on an engineering risk assessment that incorporates two groups of variables, testing quality and application requirements. The design pressure for a PE pipe is calculated for a given application and pipe material with consideration to the risk. The design factor used with the HDB in the ASTM equation is generally regulated for certain jurisdictions with consideration for various risks.

[14] Although a direct comparison is made between to the two systems, it is important to remember, the differences in the conditions and application standards.
[15] ISO 12162 and the respective ISO Effect time - temperature on expected strength standards provide guidance on selecting and applying reduction factors or use of reference curves when temperatures are above 20°C. One example is ISO 10146 for PEX compounds.

Gas engineers select the design factor within the confines of the regulations governing their jurisdiction. The resulting design pressure considers those risks calculated within the minimum safety standards of local regulations. The design pressure in ISO using the MRS equation calculates, with the minimum design coefficient, the maximum design pressure allowed for any type of fuel gas application, regardless of location (e.g. rural or urban.) Gas system design engineers must select the appropriate design coefficient for their application taking into account national and local regulation design limitations.

Using these two design equations, the design pressure for a given pipe may be different using HDB and DF (under certain jurisdictions) than when calculated with MRS and C "for the same pipe". When reviewing this Technical Report, the reader must keep in mind that one jurisdiction can view risk and corresponding consequence of failure differently than another jurisdiction for a given application.

4.2. Pressure Rating Differences for Non-Regulated Gas Gathering Systems

For gas gathering applications the gas engineer uses the same design equation in PPI TN-28. At this time, DOT Part 192 does not regulate most gas gathering applications[16], so the gas engineers generally apply the PPI HSB recommended water design factor for polyethylene pressure pipe compounds, which was 0.5 DF for PE 3408 prior to 2005, and then increased to a 0.63 DF for PE4710 compounds.

4.2.1. ASTM Pressure Rating Utilizing a 73°F HDB

Using Equation 1, the ASTM pressure rating for an SDR 11 PE3408 pipe utilizing a design factor of 0.5 for a non-regulated gas gathering application is shown below. This is the **maximum** pressure that a gas gathering company could operate their PE3408 pipeline in a non-regulated gas gathering application.

$$P = [2\ (1600)\ (.50)\ /\ (11-1)] = 160 \text{ psig}$$

The ASTM pressure rating for non-regulated gas gathering applications, utilizing the recommended design factor for polyethylene pressure pipe compounds prior to 2005 was 160 psig for an SDR 11 PE3408 pipe.

[16] PHMSA announced future intentions to regulate certain gas gathering pipelines. The timing of this initiative is unknown.

When the PPI HSB increased the design factor from 0.5 (PE3408) to 0.63 (PE4710) in 2005 for the ASTM method, the corresponding pressure rating increased from 160 psig to 201 psig.

$$P = [2 (1600) (0.63) / (11-1)] = 201 \text{ psig}$$

4.2.2. ISO Pressure Rating Utilizing an MRS (20°C, 50-years)

As stated above for unregulated gas gathering applications, the gas engineer uses the same design coefficient recommended for water. Using Equation 2, the ISO pressure rating for an SDR 11 PE 100 pipe using a minimum design coefficient of 1.25, as recommended by ISO 4427 for water applications, is shown below. This pressure rating is the **maximum** pressure that a gas design engineer could operate their PE 100 pipeline at 20°C. The gas gathering engineer has the option to increase the service design coefficient to lower the pressure rating as an added measure of safety.

$$P = [20 (10) / (11-1) (1.25)] = 16 \text{ bar} = 232 \text{ psig.}$$

The ISO maximum pressure rating for non-regulated gas gathering applications, based on the ISO minimum design coefficient of 1.25, is 16 bar or 232 psig for an SDR 11 PE 100 pipe. This maximum pressure rating must also be further reduced when operating temperatures are above 20°C (68°F) – see ISO 4437-5 Annex 5.

4.2.3. Comparison of the Pressure Ratings[14, 15]

The ISO pressure rating of 232 psig for SDR 11 PE 100 at 20C is 45% higher than the HDB pressure rating of 160 psig at 23C for the same PE pipe of the same size when compared to the ASTM pressure rating using a PE3408 pipe. This 45% difference in pressure ratings between PE 100 (232 psig) and PE3408 (160 psig) was instrumental in the PPI HSB forming an HDB/ MRS Task Group to investigate the material performance criteria and differences between the ASTM and ISO systems. At the time of this writing, the ISO PE 100 pipe pressure ratings are only 15% higher than the PE4710 pipe pressure rating for the same gas gathering pipe – or less if operating above 68°F (20°C).

5.0 SERVICE DESIGN FACTORS

5.1. Service Design Factor (0.45 DF) for Gas Distribution Applications

5.1.1. Polyethylene (PE) Gas Distribution Pipe

The code for gas distribution in Canada is CSA Z662 "*Oil and Gas Pipeline Systems*". Canada adopted the 0.4 design factor for gas distribution applications in CSA Z662 Clause 12 in 1996 – 23 years before it was adopted in the US[17]. When PE2708 and PE4710 pipe material designation codes were introduced into the Canadian PE gas standards CSA B137.4 and CSA Z662 Clause 12 around 2005, the service design factor remained unchanged. All PE compounds had been using a 0.4 service design factor since 1996. Thus, in Canada, there was no difference in pressure rating between a PE3408 and PE4710 pipe, or between a PE2406 and PE2708 pipe.

A few years after the PE2708 and PE4710 designation codes were introduced in Canada, both PE 100 and the ISO pressure rating method were introduced into the PE gas pipe standard CSA B137.4 and into the Oil and Gas Code CSA Z662 Clause 12 for gas distribution. This PE 100 classification resulted in an increase in the maximum pressure rating as shown below at 20°C.

In Canada, the maximum ASTM pressure rating, using Equation 1 for a PE4710 SDR 11 pipe, with the CSA Z662 Clause 12 recommended service design factor of 0.4 is shown below at 73°F:

$$P = [2\ (1600)\ (.4)\ /\ (11\text{-}1)] = 128 \text{ psig}$$

With the PE 100 compound, the maximum pressure rating using Equation 2 for a PE 100 SDR 11 pipe, with a minimum design coefficient of 2.0 as recommended by CSA Z662 Clause 12 is shown below at 20°C:

$$P = [20\ (10)\ /\ (11\text{-}1)\ (2.0)] = 10 \text{ bar} = 145 \text{ psig.}$$

The PE 100 compound had a maximum pressure rating ~13% higher (145 vs 128) than the PE4710 compound. **However, many times PE4710 and PE 100 are the SAME compound.** Further, many PE compounds were dual listed in PPI TR-4 as both a PE4710 and as a PE 100 compound. Since both compounds were included in the product standard CSA B137.4 and the code CSA Z662 Clause 12, the Canadian gas operators wanted these two compounds to have the same pressure rating. In an effort to

[17] R. Fox, G. Palermo. Changes to CSA Z662 Oil and Gas Pipeline Systems to incorporate Higher Performance Plastic Pipe. Plastics Pipes XV, Vancouver, 2010.

alleviate this difference in the pressure ratings between PE4710 and PE 100, CSA Z662 Clause 12 adopted a 0.45 service design factor for certain PE4710 and PE2708 compounds. In order to justify this higher service design factor, the CSA Z662 Clause 12 gas companies decided to impose very stringent slow crack growth (SCG) and rapid crack propagation (RCP) requirements. They also introduced the term "PLUS" after the pipe material designation code to differentiate compounds that could use the 0.45 DF.

The 2015 edition of CSA Z662, Clause 12 reads as follows:

> **"12.5.2.3 PLUS Performance PE compounds**
>
> The minimum PENT value for HDB-rated plus performance PE compounds using the 0.45 design factor shall be 2000 hours, and the minimum RCP Small-Scale Steady State value shall be 1000 kPa at 0°C per Clause 12.4.3.6. These plus performance PE compounds that qualify for a 0.45 design factor shall be designated with a PLUS after the pipe material designation code; for example, PE 2708 PLUS or PE 4710 PLUS."

With this change, the pressure rating at 73°F using Equation 1 for an SDR 11 PE4710 PLUS pipe, with the CSA Z662 Clause 12 recommended design factor of 0.45 is:

$$P = [2\ (1600)\ (.45)\ /\ (11\text{-}1)] = 144 \text{ psig}$$

With the introduction of the 0.45 design factor, the pressure rating for PE4710 was increased from 128 psig to 144 psig, thus making the PE 4710 PLUS pipe pressure rating at 73°F (23°C) equivalent to the ISO PE 100 pressure rating of 145 psig at 20°C (68°F). The PE 100 pressure rating at 73°F would be further derated according to ISO 4437-5 Annex A. This PLUS designation is only used in Canadian standards. It should be emphasized that this increased design factor of 0.45 is only allowed in Canada for PE materials that have a very high resistance to slow crack growth, as measured by the PENT requirement of 2000 hours. Where this higher DF is utilized is up to the design engineer and class location of the system. Many times lower design pressures are mandated.

5.1.2. Crosslinked Polyethylene (PEX) Gas Distribution Pipe

A similar revision has been made to the Canadian product standard for PEX (crosslinked PE) gas distribution pipe – CSA B137.19 "Crosslinked polyethylene (PEX) piping systems for gas services*"*. Section 4.0 "Design" currently states:

> *4.1.1.2.2*
> *The design stress (DS) shall be the HDB times the design factor (F) for the application. For example, for gas distribution applications,* ***F is 0.45*** *and the corresponding design stress is specified in Table 8.*
>
> **Table 8**
> **HDB Design Stress table**
> (See Clause 4.1.1.2.2)
>
> | Pipe material designation code | HDB MPa | DS for Gas Distribution MPa |
> |---|---|---|
> | PEX XX06 | 8.62 | 3.88 |
> | PEX XX08 | 11.03 | 4.96 |

Since all PEX pipe has very high SCG and RCP performance, there is no need for the "PLUS" designation. PEX pipe, meeting the requirements specified in B137.19, qualifies for the 0.45 service design factor in gas distribution applications. Thus, in this Canadian CSA B137.19 product standard, PEX 80 (MRS) has the same pressure rating as PEX XX06 (HDB) and PEX 100 (MRS) has the same pressure rating as PEX XX08 (HDB).

5.2. Service Design Factor (0.71 DF) for Gas Gathering Applications

5.2.1. Polyethylene (PE) Gas Gathering Pipe

As stated previously, the design factor used for gas gathering applications is often the same as the design factor used for water applications, which in turn is the PPI HSB recommended DF for PE compounds of 0.5 or 0.63 DF. In the case of Canadian PE water pipe, the product standard is CSA B137.1 "Polyethylene (PE) pipe, tubing, and fittings for cold-water pressure services*"*. When PE 2708 PLUS and PE 4710 PLUS were added to CSA B137.4 for gas applications (with its higher design factor of 0.45), the members of the CSA B137 Technical Committee decided to also add PE 2708 PLUS and PE 4710 PLUS to CSA B137.1 for water applications. The design factor selected for these water applications was 0.71, as this design factor follows the R20 preferred number series with an increment of 12.5%[18]. The 12.5% increase in design factor from 0.63 to 0.71 for water applications is equivalent to the 12.5% increase in design factor from 0.4 to 0.45 for gas applications. Thus, the CSA B137 Technical Committee agreed to this increase in design factor from 0.63 to 0.71 for water applications for compounds in CSA B137.1 meeting the PLUS requirement, because this was consistent with the same increase in design factor for PLUS compounds that the CSA B137 Technical Committee had already approved in CSA B137.4 for gas applications.

Section 4.2 “Materials” in CSA B137.1 now states:

4.2.3 Long-term hydrostatic strength

PE compound used in the manufacture of pipe shall have a hydrostatic design stress for water at 23 °C in accordance with the values in Table 1, when tested in accordance with Clause 6.6.4 of CSA B137.0.

Table 1
Hydrostatic design stress for PE compounds
(See Clause 4.2.3.)

Compound	Hydrostatic design basis, MPa	Design factor	Hydrostatic design stress, MPa
PE 1404	5.52	0.5	2.76
PE 2708	8.62	0.63	5.52
PE 2708 PLUS	8.62	**0.71**	6.12
PE 3608	11.03	0.5	5.52
PE 4710	11.03	0.63	6.89
PE 4710 PLUS	11.03	**0.71**	7.83

[18] ISO 3-1973 Preferred Numbers – Series of preferred numbers. International Organization of Standards. Switzerland.

5.2.2. Crosslinked Polyethylene (PEX) Gas Gathering Pipe
API (American Petroleum Institute) recently published a standard for PEX pipe used in gas gathering applications - API Specification 15PX "Specification for Crosslinked Polyethylene (PEX) Line Pipe" published in September 2018. The Scope of this new standard is:

1.2 Scope
This specification covers PEX line pipe utilized for the production and transportation of oil, gas, and non-potable water. The piping is intended for use in new construction, structural, pressure-rated liner, line extension, and repair of both aboveground and buried pipe applications.

1.3 Service Conditions
The standard service conditions for the API 15PX standard pressure rating are as follows:
a) Standard pressure ratings in non-chemically-aggressive fluids,
b) Service temperature range: -50°C to 95°C,
c) The fluid environment is oil, gas, and nonpotable water and combinations thereof.

This API Standard for PEX has two different pressure rating methods. One method is based on the ASTM HDB system. The other method is based on the ISO MRS systems. Since both pressure rating methods are in the same standard, the members of the API 15PX Technical Committee decided that the resulting pressure ratings should be equivalent, independent of which pressure rating method was used. The API gas gathering members discussing PEX pipe pressure rated by the ASTM method (PEX XX08) and by the ISO method (PEX 100) in the same standard went through similar deliberations as the Canadian gas operators who discussed PE pipe pressure rated by the ASTM method (PE4710) and the ISO method (PE 100) in their same standard. In both situations, these organizations wanted consistency between these two pressure rating methods for the same products that are specified in the same product standard.

PEX pipe had already been successfully used for gas gathering applications throughout the world for many years using the ISO system. Thus, in order for the pressure rating using the ASTM method to be equivalent to the pressure rating using the ISO method, an ASTM design factor of 0.71 was selected. The API members based this selection of 0.71 for the ASTM design factor on the many successful years of operation for PEX pipe using the ISO pressure rating method and on the stringent performance requirements for PEX pipe in the API standard. Since the same PEX pipe product was being specified in API 15PX using the ASTM method and the ISO method, the API members decided that the PEX pipe pressure rating using the ASTM method should be the same as the PEX pipe pressure rating using the ISO method, which had many successful years of operating at this pressure rating.

API 15PX discusses the ASTM pressure rating method in Section 4.3 “Determining the Maximum Working Pressure”, as follows.

> 4.3.1.5 The value for the maximum working pressure for multiphase fluids, wet natural gas, and liquid hydrocarbons is at the intersection of the DR column and the HDB row in Table 3, and includes the **application of a DSF (design service factor) of 0.71.**

This API 15PX standard now recommends a DSF of 0.71 in the ASTM HDB design equation for PEX pipe used in gas gathering applications both in the US and in Canada.

A similar revision has been made to the Canadian product standard for PEX gas gathering pipe – CSA B137.19 “Crosslinked polyethylene (PEX) piping systems for gas services”. Section 4.0 “Design” currently states:

> 4.1.1.2.2
> The design stress (DS) shall be the HDB times the design factor (F) for the application. For gas gathering applications, **F is 0.71** and the corresponding design stress is specified in Table 8.
>
> **Table 8**
> **HDB Design Stress table at 23°C**
> (See Clause 4.1.1.2.2)

Pipe material designation code	**HDB MPa**	**DS for Gas Gathering MPa**
PEX XX06	8.62	6.12
PEX XX08	11.03	7.83

Since all PEX pipe has very high SCG and RCP performance, there is no need for the “PLUS” designation. PEX pipe, meeting the specified requirements, qualifies for the 0.71 design factor for use of PEX in gas gathering applications. Again, the CSA B137 Technical Committee approved this 0.71 design factor for PEX gas gathering applications in CSA B137.19 because it had already approved the 0.71 design factor for PE water applications in CSA B137.1 and the 0.45 design factor for PE gas distribution applications in CSA B137.4

The CSA and API members approved this design factor of 0.71 for PEX compounds based on the stringent requirements for PEX and the successful use of PEX pipe at the higher pressure ratings in many countries.

CSA Z662-19 Standard “Oil and Gas Pipeline Systems” currently uses a design factor of 0.5 for PEX for regulated gas gathering in Canada. Additionally, ASTM standards currently recommend a design factor of 0.5 for PEX. The PPI HSB is considering increasing the recommended design factor for PEX from 0.5 to 0.63, as they did for PE in 2005.

6.0 SUMMARY

This technical report provides a historical review of two design methods, ASTM (HDB) and ISO (MRS), used in gas distribution and gas gathering applications. This is not an endorsement for either the ASTM or ISO pressure-rating method. **PPI does not recommend one method or the other – they are both technically sound methods that are used by the industry with a different bases for establishing an appropriate design stress. It is important to understand that a pipe made from a PE compound operating at a higher pressure has a reduced margin of safety than a pipe made from the same compound operating at a lower pressure. It is always the responsibility of the system design engineer to understand these factors and mitigate the risk of failure. This technical report simply provides a historical overview and current status of these two methods.**

This technical report also provides a review of changes made to the design factors during the past few years to several industry standards, such as ASTM, CSA, and API.

There are currently two standard writing organizations that recommend a service design factor of 0.71 for water and gas gathering applications. These are detailed in their respective standards:

- CSA B137.1 for PE water pipe
- CSA B137.19 for PEX gas gathering pipe
- API 15PX for PEX gas gathering pipe

ANNEX A. PRESSURE RATINGS FOR SDR 11 PE AND PEX PIPES

For comparison purposes, below are tables that summarize the pressure ratings for the design factors and design coefficients reviewed in this PPI Technical Report for SDR 11 PE and PEX pipes.

Table A 1. Pressure Ratings for SDR 11 PE Pipes

Application	PE Compound	Design Factor	Design Coefficient (C Factor)	Pressure Rating at 73°F, psig
Gas Distribution	PE3408	0.32		102
	PE4710	0.40		128
	PE 4710 PLUS	0.45		144
	PE 100		2.0	145 *at 20°C, 50-years 140 *at 23°C, 50-years
Gas Gathering	PE3408	0.50		160
	PE4710	0.63		200
	PE 4710 PLUS*	0.71		227
	PE 100		1.25	232 at 20°C, 50-years 225 *at 23°C, 50-years

*CSA Z662-19 recognizes PE 4710 PLUS designation for gas distribution but does not recognize the PE 4710 PLUS designation for gas gathering.

Table A 2. Pressure Ratings for SDR 11 PEX Pipes

Application	PEX Compound	Design Factor	C Factor	Pressure Rating at 73°F, psig
Gas Distribution	PEX XX08*	0.32		102
	PEX XX08	0.40		128
	PEX XX08	0.45		144
	PEX 100		2.0	145 at 20°C, 50-years
Gas Gathering	PEX XX08	0.50		160
	PEX XX08	0.63		200
	PEX XX08	0.71		227
	PEX 100		1.25	232 at 20°C, 50-years

*The first two digits in the PEX pipe material designation code (XX) are for chlorine resistance and outdoor storage.