Comparison Between PE 4710 (PE 4710 PLUS) and PE 100 (PE 100+, PE 100 RC)

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Abstract

The scope of this paper is to clarify the various pipe material designation codes and other terms (PE 4710, PE 4710 PLUS, PE 100, PE 100 RC and PE 100+) that are used in the piping industry for high density polyethylene (HDPE) materials. These are the benchmark "high performance" HDPE materials used worldwide for a variety of plastic piping applications. In this paper, I will first describe the two pressure ratings methods, ASTM D 2837 and ISO 9080, and the corresponding pipe material designation codes that are used throughout the industry. I will then review the properties for each HDPE material, and the requirements for its pipe material designation code. I will explain how these HDPE pipe material designation codes are similar and how they are different. I will compare the pressure ratings for each HDPE material using the appropriate design factor or design coefficient. Finally, I will discuss PPI TR-4 and the listing of PE 4710 and PE 100 materials on the PPI website, the PE 100+ Association and the listing of PE 100+ materials on the PE 100+ website, and the new terms PE 4710 PLUS and PE 100 RC.

ASTM Pressure Rating Method

The ASTM pressure rating method utilizes pipe samples tested at a constant temperature with the linear log stress – log time regression line extrapolated to 100,000 hours (11 years) (1). This extrapolated value is called the long-term hydrostatic strength (LTHS) and the categorized value of the LTHS is called the HDB (Hydrostatic Design Basis) in accordance with ASTM method D 2837. These HDB values are published in PPI TR-4 (2), which is available on the PPI website www.plasticpipe.org. The HDS (hydrostatic design stress) is the product of the HDB and the design factor for water, which is 0.50.

The design engineer uses the pressure rating formula below to calculate the maximum operating pressure (MOP) for his PE pipe:

$$MOP = [2 (HDB) (F) / (SDR – 1)]$$

Where: MOP = maximum operating pressure, psig
HDB = hydrostatic design basis, psi
F (design factor) = 0.32 for US gas pipe applications
= 0.40 for Canada gas pipe applications
= 0.50 for water pipe applications
SDR = standard dimension ratio

An example calculation for an SDR 11 PE 3408 pipe with an HDB of 1600 psi used for US gas pipe applications is:

$$MOP = [2 (1600) (.32) / (11-1)] = 100 \text{ psig.}$$

This is the maximum operating pressure or pressure rating for buried SDR 11 PE 3408 pipe using the industry recommended design factor (F) of 0.32 for US gas piping applications.

Another example calculation for an SDR 11 PE 3408 pipe with an HDB of 1600 psi used for water pipe applications is:

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

This is the maximum operating pressure or pressure rating for buried SDR 11 PE 3408 pipe using the industry recommended design factor (F) of 0.50 for water piping applications.

The design engineer may use a lower design factor if deemed appropriate for the installation. An example of this is if the PE pipe is buried in soil contaminated with a liquid hydrocarbon. PPI TR-9 provides guidance on the chemical design factor (F_C). The actual design factor used is then F times F_C.

ASTM Pipe Material Designation Code

In the ASTM pipe material designation code system the plastic is identified by its standard abbreviated terminology in accordance with ASTM D 1600, "Standard Terminology Relating to Abbreviations, Acronyms, and Codes for Terms Relating to Plastics", followed by a four or five digit number (2). The first two or three digits, as the case may be, code the material's ASTM classification (short-term properties) in accordance with the appropriate ASTM standard specification for that material. The last two digits of this number represent the PPI recommended HDS (0.5 design factor) at 73^{o}F (23^{o}C) divided by one hundred. An example for a PE material follows:

- PE 3408 is a polyethylene (the PE abbreviation is in accordance with ASTM D 1600) classified as a grade PE 34 with a density cell class of 3 and a slow crack growth cell class of 4 (in accordance with ASTM D 3350). It has an 800-psi maximum recommended HDS (0.5 design factor) at 73°F (23°C).

The ASTM pipe material designation code provides information on a physical property (density), a performance property (slow crack growth) and the hydrostatic design stress for water applications (HDB times the water design factor).

ISO Pressure Rating Method

The ISO pressure rating method utilizes pipe samples tested at three different temperatures with the linear log stress – log time 20°C regression line extrapolated to 480,000 hours (50 years). The lower confidence level of the extrapolated value is called the lower predictive level (LPL) and the categorized value of the LPL is called the MRS (minimum required strength) in accordance with ISO 9080 and ISO 12162. These MRS values are also published in PPI TR-4 (2).

The design engineer uses the pressure rating formula below to calculate the maximum operating pressure (MOP) for his PE pipe:

$$MOP = [20\,(MRS) / (SDR - 1)\,(C)]$$

Where:

MOP = maximum operating pressure, bar
MRS = minimum required strength, MPa
C (design coefficient) = minimum of 1.25 for water pipe
= minimum of 2.0 for gas pipe
SDR = standard dimension ratio

An example calculation for an SDR 11 PE 100 pipe with an MRS of 10 MPa used for gas pipe applications is:

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

This is the maximum operating pressure or pressure rating for buried SDR 11 PE 100 pipe using the gas standard ISO 4437 recommended minimum design coefficient (C) of 2.0 for gas applications (3).

Another example calculation for an SDR 11 PE 100 pipe with an MRS of 10 MPa used for water pipe applications is:

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

This is the maximum operating pressure or pressure rating for buried SDR 11 PE 100 pipe using the water standard ISO 4427 recommended minimum design coefficient (C) of 1.25 for water applications.

The design engineer may use a higher design coefficient if deemed appropriate for the installation. An example of this is if PE pipe is buried in soil contaminated with a liquid hydrocarbon. Individual countries may provide guidelines on the use of appropriate design coefficients for various installations.

PE 100 Materials (ISO Pipe Material Designation Code)

The ISO pipe material designation code uses similar letters for the type of material as the ASTM code. Examples are PE for polyethylene, PA for polyamide or PVC for poly vinyl chloride. These letters are followed by numbers that are simply the MRS (from ISO 9080 and ISO 12162) times ten. For example, PE 100 is a PE material with an MRS of 10 MPa. Note that there are no physical property or performance requirements in the ISO pipe material designation code, or information about the design coefficient. The ISO pipe material designation code is simply the material and the MRS. One industry myth is that all PE 100 materials have superior SCG and RCP properties. This is not true. The term PE 100 simply means that the material is PE and the MRS is 10 MPa. Generally, the SCG and RCP performance requirements for PE 100 materials are in the product standards.

PE 100+ Association

It is important to note that the term "PE 100+" is NOT a pipe material designation code. It is not used for pressure rating calculations. It is the name of a trade association made up of PE resin manufacturers who produce very high performance bimodal PE 100 materials. As just stated the pipe material designation code PE 100 only specifies the type of material and the MRS. The bimodal PE 100 materials have superior slow crack growth (SCG) and rapid crack propagation (RCP) resistance properties, and these bimodal PE 100 resin producers wanted these superior properties to be recognized. In forming their trade association, they specify very stringent SCG and RCP requirements for PE 100+. The SCG requirement is the notched pipe test (NPT) with a required value of 500 hours, and the RCP requirement is an S4 (small scale steady state) critical pressure of 10 bar.

In addition to these very stringent performance requirements, the PE 100+ Association also has a rigorous third-party testing program. The resin manufacturers are audited and samples are tested every few months to assure these bimodal PE 100 materials continue to meet the stringent performance requirements.

All of the PE 100 materials that meet the stringent requirements for a PE 100+ are listed on their website – www.pe100plus.com. In order to maintain their listing on this website, the PE 100 materials must continue to demonstrate they meet the performance requirements through the rigorous SCG and RCP auditing program.

PE 100 RC Materials

PE 100 RC is also not a pipe material designation code. This is a term that was developed in Europe to designate PE 100 materials that have even higher slow crack growth (SCG) resistance than PE 100+. The "RC" refers to "resistance to cracking". These PE 100 RC materials are used in especially demanding applications where a very high level of SCG resistance is required. One such application is for gas companies to use the natural backfill when installing PE 100 RC pipe in rocky areas, and avoid the cost of importing sand backfill. Their very high resistance to SCG will prevent any rock impingement failures. These PE 100 RC materials typically have PENT values over 10,000 hours.

PE 100 RC is not yet recognized in an ISO product standard or in any country product standard, and it is also not an organization like PE 100+. For now, it is simply a term to designate PE 100 materials with a very high level of SCG resistance. There were several papers at PP XIV discussing PE 100 RC materials, and there will also be several papers at PP XV discussing these PE 100 RC materials.

PE 4710 Materials

When the superior performing bimodal PE 100 materials were brought to North America, they were pressure rated as a PE 3408 using the ASTM D 2837 pressure rating method. Many of the key performance attributes of PE 100 were not recognized in the PE 3408 pipe material designation code. Also, as seen from the above calculations, a PE 100 SDR 11 pipe could be operated at 145 psig using the ISO pressure rating system for a gas application. That same SDR 11 pipe as a PE 3408 could only be operated at 100 psig using the ASTM pressure rating method for the same gas application. That is a 45% difference for the same PE material, the same pipe SDR, for the same application.

In an effort to bring the ASTM and ISO systems closer together, PPI in conjunction with the Hydrostatic Stress Board (HSB) formed an HDB/MRS committee. The purpose of this committee was to define the high performance parameters through ASTM standards that would justify a higher design factor of 0.63 for water applications or 0.40 for gas applications for these higher performing PE materials. This 25% increase in design factor would reduce the gap between ASTM and ISO from 45% to 15%. Several changes to ASTM standards were required to accomplish this. The materials that qualify for this higher design factor are called "high performance" PE materials and require a PENT value (ASTM F 1473) of 500 hours. The new pipe material designation code for PE 3408 became PE 4710 to indicate that these high performance materials qualified for the higher design factor.

This new ASTM pipe material designation code of PE 4710 again provides a physical property (density), a performance property (slow crack growth) and the design stress for water applications (HDB times the water design factor). The PE 4710 density is higher than PE 3408– "4" (0.947 to 0.955 g/cc) compared to "3" (0.940 to 0.946 g/cc). The slow crack growth resistance is considerably higher for the high performance PE 4710 – "7" (500 hours PENT) compared to "4" (10 hours PENT). This is the key requirement that justifies the higher design factor of 0.63 for water. The HDB is still 1600 psi, but with the higher water design factor of 0.63, the hydrostatic design stress is 1000 psi, and thus the "10" in the pipe material designation code.

PE 4710 PLUS Materials

In Canada, CSA Z662 Clause 12 had already increased the design factor for gas applications from 0.32 to 0.40 in 1996. As a result when PE 4710 was introduced in Canada there was no difference in pressure rating compared to a PE 3408. The Canadian gas companies wanted to recognize the higher performance for the superior bimodal PE materials, and so they introduced a 0.45 design factor. With this even higher design factor of 0.45, the pressure rating for PE 4710 and PE 100 became the same. Canada actually closed the gap between the ASTM and ISO pressure rating methods with the introduction of this 0.45 design factor for gas piping applications in CSA Z662 Clause 12 (4).

> *12.4.2.2*
> *The design factor (F) to be used in the design formula in Clause 12.4.2.1 (a) for HDB-rated materials shall be 0.40, or 0.45 for PLUS performance PE compounds described in 12.5.2.3.*

To indicate that a PE material could use the higher 0.45 design factor, Clause 12 introduced the term "PLUS" after the pipe material designation code – for example, PE 4710 PLUS.

The Canadian gas companies wanted to assure that only the superior performing bimodal PE materials would qualify for the higher design factor (PLUS). To assure a very high level of slow crack growth resistance, Clause 12 requires a PENT value of 2000 hours. This is consistent with the 2000-hour PENT requirement for PE 100 materials in Clause 12. To assure a very high level of rapid crack propagation resistance, Clause 12 requires an S4 critical pressure of 10 bar (1000 kPa) at 0°C (32°F). This is consistent with the S4 RCP critical pressure requirement for PE 100 materials in Clause 12. This is also consistent with the RCP requirement for PE 100+ materials. Thus the HDB-rated PE 4710 PLUS and the MRS-rated PE 100 have the same stringent SCG and RCP requirements in Clause 12, as shown below.

> ***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℃ 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.*

Pressure Rating Comparisons

The Tables below compare the maximum operating pressure (MOP) for HDPE (high density PE) materials used in SDR 11 pipe for gas and water applications. I have not included PE 100+ or PE 100 RC because they have the same pressure rating as PE 100.

Maximum Operating Pressure (MOP) for HDPE SDR 11 Pipe – Gas Applications

	PE 3408	PE 4710	PE 4710 PLUS	PE 100
HDB, psi	1600	1600	1600	
MRS, MPa				10
Design factor	0.32 (US) 0.40 (Canada)	0.40	0.45	
Design coefficient				2.0
MOP for SDR 11, psig	100 (US) 125 (Canada)	125	145	145

From this Table, you can see that:
- the pressure rating for PE 3408 and PE 4710 are the same – for Canada,
- the pressure rating for PE 4710 PLUS is 15% higher than PE 4710, and
- the pressure rating for PE 4710 PLUS and PE 100 are the same.

Maximum Operating Pressure (MOP) for HDPE SDR 11 Pipe – Water Applications

	PE 3408	PE 4710	PE 100
HDB, psi	1600	1600	
MRS, MPa			10
Design factor	0.5	0.63	
Design coefficient			2.0
MOP for SDR 11, psig	160	200	232

From this Table, you can see that:

- the pressure rating for PE 3408 is 25% less than PE 4710
- the pressure rating for PE 4710 is 15% less than PE 100
- there is no PE 4710 PLUS for water applications

For gas applications in Canada, the PE 4710 PLUS pipe material designation code has a physical property requirement (density), a more stringent slow crack growth resistance requirement of 2000 hours PENT, AND a new requirement for rapid crack propagation of 10 bar S4 critical pressure.

Summary

The table below summarizes the pipe material designation codes and other terms that were discussed in this paper.

Material	Physical Property	SCG	RCP	HDB or MRS
PE 100	-	-	-	MRS
PE 100 +	-	500 hours NPT	10 bar S4 critical pressure	MRS
PE 100 RC		10,000 hours PENT	-	MRS
PE 3408	Density	10 hours PENT	-	HDB and F = 0.50 for water
PE 4710	Density	500 hours PENT	-	HDB and F = 0.63 for water
PE 4710 PLUS	Density	2000 hours PENT	10 bar S4 critical pressure	HDB and F = 0.63 for water or, F = 0.45 (gas in Canada)

References

1. E. F. Palermo, “High Performance Bimodal PE 100 Materials For Gas Piping Applications”, AGA Operations Conference, 2005.
2. PPI TR-4, “PPI Listing of Hydrostatic Design Basis (HDB), Hydrostatic Design Stress (HDS), Strength Design Basis (SDB), Pressure Design Basis (SDB), and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials and Pipe”
3. ISO 4437, “Buried polyethylene (PE) pipes for the supply of gaseous fuels — Metric series — Specifications”.
4. R. Fox and E. F. Palermo, “Changes to CSA Z662 ‘Oil and Gas Pipeline Systems’ to Incorporate Higher Performance Plastic Pipe”, PP XV, 2010.