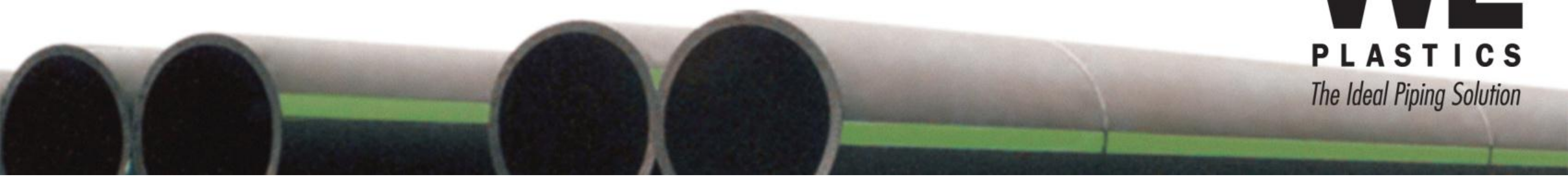
WL123 – HIGH-PERFORMANCE PE4710



What is High-Performance PE4710 Polyethylene?

High-performance polyethylene is an improved polyethylene compound for pressure pipe that is designated PE4710. Compared to conventional pressure piping materials such as PE3408, several important performance characteristics are significantly enhanced. PE3408 does not meet PE4710 requirements.

- Higher density

  Higher density increases tensile strength, stiffness and chemical resistance. PE3408 materials (D 3350 cell classification 345464) have base resin densities above 0.940 to 0.947 gm/cc, and with 2% carbon black, density is 0.949 to 0.956 gm/cc. PE4710 materials (D 3350 cell classification 445574) have base resin densities above 0.947 to 0.955 gm/cc, and with 2% carbon black, density is above 0.956 to 0.964 gm/cc.

- SCG cannot occur before 50 years

  For PE pressure piping materials, slow crack growth, SCG, is the long term failure mode. SCG is not brittleness. Stress such as internal pressure causes cracks to develop and grow through the pipe wall from stress concentrations. To qualify as PE4710, testing and analysis must show that a transition to SCG (a "knee" or downturn in the stress rupture curve) does not occur before 438,000 hours (50 years) – a 4 to 1 increase over conventional HDPE – and must show that the estimated strength will be correct at least 90% of the time – a 33% reduction in permissible pipe test data variability.

  ASTM D 2837 and PPI TR-3 are used to determine the hydrostatic design basis, HDB, which is based on ductile performance. HDB for thermoplastic pressure piping materials including PVC, CPVC, PP, PE, ABS, PB, PA, etc., is a 100,000 hour stress rating for pressure piping design. The ASTM D 2837 method does not accommodate the SCG failure type; therefore, conventional HDPE materials must prove ductility for the HDB rating at 100,000 hours. PE4710 must demonstrate ductile performance beyond 50 years, four times longer than conventional HDPE. ASTM D 2837 requires a data analysis to show that the HDB will be at least 85% correct. PE4710 requirements specify that the HDB will be at least 90% correct.

- Up to fifty-fold increase in SCG resistance

  PE3408 materials (D 3350 cell classification 345444) have PENT (ASTM F 1473) SCG resistance of at least 10 hours. PENT test research empirically correlated 25-35 hours PENT SCG resistance to 100 years in pressure gas service. PE4710 materials (D 3350 cell classification 445474) must have at least 500 hours PENT SCG resistance, a 50 to 1 increase – WL Plastics PE4710 compounds typically exceed 2500 hours – providing greatly improved SCG resistance compared to PE3408 compounds. This means that the potential for SCG failure, the long-term failure mode for PE pipe, is extremely remote.

The High-Performance PE4710 Advantage

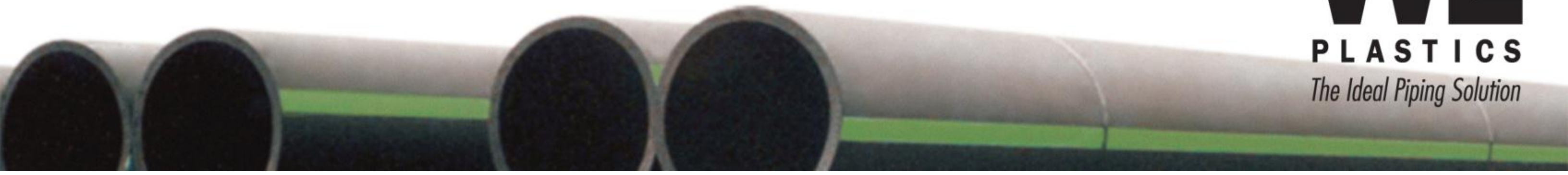
- PE4710 pipe is pressure rated higher than PE3408 pipe for the same DR, or for PE3408 and PE4710 pipes that have comparable pressure ratings, PE4710 provides a flow capacity increase.

Table 1 Comparative Pipe Pressure Ratings for Water at 80°F and Lower, psi

DR	7	7.3	9	11	13.5	15.5	17	21	26	32.5
PE4710 PR	336	320	252	202	161	139	126	101	81	64
PE3408 PR	267	254	200	160	128	110	100	80	64	51

Table 2 PE4710 vs. PE3408 Water Flow Capacity Increase, %

System Pressure, psi	100	150	200	250
PE4710 Capacity Increase vs. PE3408, %	7.5	10.8	15.4	19.8



Why PE4710 has a higher pressure rating

In North America, pipe pressure rating is determined using the hydrostatic design stress, HDS, for the material and the application. HDS is the HDB multiplied by a design factor, DF, for an application. To avoid confusion with safety factors that are usually divisors applied to reduce short term mechanical strength, a design factor multiplier is used. Design factors can vary for different applications and regulatory requirements.

As the thermoplastic pipe industry began about a half century ago, the PPI Hydrostatic Stress Board developed design factors to address reductions to laboratory derived design stress ratings to address uncertainty in material, pipe manufacture, handling, installation, application operating characteristics, and unknown factors. The result was a 0.50 design factor for thermoplastic pressure water pipe service that is used throughout North America for most thermoplastic pressure piping materials. It was developed by determining component design factors for water application as follows:

- 1.00 starting basis
- 0.25 for materials variability from lot to lot, and for variability in testing and test methods
- 0.05 for extrusion quality variation
- 0.10 to extend the HDB from 11.4 years to 50 years
- 0.20 for pressure surge variations (based on PVC water hammer capacity)
- 0.20 for handling and installation
- 0.20 for unknown factors

When summed, the overall design factor from these components is 2.00, the inverse being 0.50. Over the years, the 0.50 DF has proved to be conservative and generally satisfactory for thermoplastic water piping materials including PVC, CPVC, ABS, PP and conventional PE, and for general thermoplastic pressure piping applications.

However, as presented above, PE4710 materials demonstrate a higher level of performance, superior ductility and resistance to fracture at higher stress. These higher performance properties allow higher internal pressure without risk of service life reduction. PE4710 materials must demonstrate higher performance by qualifying against higher PPI standards for a 0.63 design factor for water and comparable applications. Using the same technical basis as that used for the 0.50 DF, the 0.63 DF is derived as follows:

- 1.00 starting basis
- 0.25 for materials for variability in testing, test methods, and lot to lot material variations

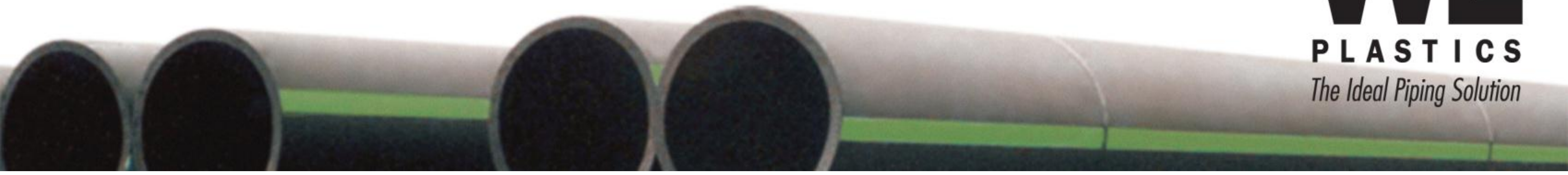
  Significantly higher requirements for HDB pipe test data quality and analysis and substantiation to prove ductility beyond 50 years reduce material variability and do not require a design factor component that extends the HDB to a 50-year value.

- 0.05 for extrusion quality variation

  Lot to lot material variations are reduced resulting in materials having more consistent processability, thus reducing the extrusion quality variability design factor component.

- 0.30 for operation, handling, installation and unknown factors

  The original 0.50 design factor allocates 0.20 for surge allowance, 0.20 for handling and installation and 0.20 for unknown factors. However, the 0.20 surge allowance is based on limiting PVC surge pressure to prevent bursting and disjoining. In contrast, high performance PE materials tolerate far higher surge pressure and piping joints are fully restrained. For a typical 100 psi water system, PE4710 provides for momentary surge pressures ***above*** the steady pressure rating from instantaneous water velocity changes up to 10 fps.



The remaining allowances for handling, installation, and unknown factors, are combined at 0.30. PE4710 materials have higher density, higher molecular weight, and higher SCG resistance, which provide greater toughness and better resistance to abrasion, chemicals, and improved elevated temperature performance. This ensures that PE4710 pipes are conservatively rated for the application, and that higher pressure ratings from the 0.63 design factor are derived without increased risk.

This derivation yields a conservative overall water service design factor for PE4710 of 1.60 (0.63 DF) *without increased risk of premature failure or reduction in service life potential*.

Thermoplastic pipes are pressure rated using the HDB, DF and DR of the pipe as follows:

$$PR = \frac{2 \times HDB \times DF}{(DR - 1)} = \frac{2 \times HDS}{(DR - 1)}$$

Thus pressure ratings for PE4710 and PE3408 DR 11 pipes for ambient temperature water at are:

PE4710 DR 11: $PR = \frac{2 \times 1000}{(11 - 1)} = 200\,psi$ PE3408 DR 11: $PR = \frac{2 \times 800}{(11 - 1)} = 160\,psi$

PE4710 vs. PE100 – Reality vs. Myth

A mythology has developed around PE100 in North America primarily from unfamiliarity and lack of understanding. PE100 is an ISO designation for a grade of pressure rated PE material. The designation means simply that the material is polyethylene, PE, and that the material qualifies for a 10 MPa (100 bar, 1450 psi) MRS rating at 20°C (68°F); nothing more; nothing less. There are also PE80 and PE63 polyethylene materials that have MRS ratings of 8.0 MPa (80 bar, 1160 psi) and 6.3 MPa (63 bar, 914 psi) respectively at 20°C (68°F). MRS, minimum required strength, is a categorized long-term strength rating similar to HDB, but it is developed using ISO standards 9080 and 12162, which together are roughly similar to ASTM D 2837. However, MRS and HDB are ***not*** the same. Some of the differences between ISO and ASTM methods for characterizing long-term material strength are:

- **Rating temperature – MRS at 20°C (68°F) vs. HDB at 73°F (23°C)**

  All thermoplastics have greater strength at lower temperatures.

- **Rating time – MRS at 50 years (438,300 hours) vs. HDB at 11.4 years (100,000 hours)**

  MRS and HDB long-term material strength ratings are both based on statistical projections (estimates) of strength at a future time. ISO uses a more complex statistical formula, and extends its estimate further into the future, but as statistical estimates are extended farther and farther into the future, prediction accuracy and reliability decrease. For both ISO and ASTM methods, the future strength projection is on logarithmic scales, that is, each scale point increase is 10 to 1 – 1, 10, 100, 1000, 10,000, 100,000, 1,000,000, etc. Both methods require test data up to 10,000 hours, and typically projections to the next scale point (10 times further) have good reliability. To increase projection reliability beyond the first scale point, ISO applies slightly tighter limits on data variability, and determines the MRS value at a lower confidence limit; HDB is a mean (average) value.

- **Validation – ISO permits a ductile-brittle transition "knee" within the rating period; ASTM does not**

  The ISO 9080 formula for estimating long-term strength in the future allows the use of brittle (SCG) failure data and ductile failure data, and permits a knee or downturn in the stress-rupture curve before the projected rating time. The ASTM D 2837 method requires validation to demonstrate that a knee in the stress rupture curve does not occur within the rating time. Substantiation demonstrates that the stress rupture curve extends to 50 years before the onset of SCG failure.

- **MRS and HDB are not the same, and do not translate**

This is because the statistical methods used to determine MRS and HDB ratings are different. However, the same material can be rated under both systems. A PE3408 may be a PE80 or a PE100 under the ISO system; likewise, a PE100 may be a PE4710 or a PE3408 under the ASTM system.

- **MYTH – PE100's are high performance PE materials.**

  PE100 identifies only a material and a strength rating. Nothing in the PE100 designation or the ISO stress rating method identifies high performance properties or sets high performance requirements. The PE4710 designation, however, can only be achieved by meeting high performance requirements. Only the very best PE100 materials may qualify as PE4710.

- **MYTH – PE100 pipe has a higher pressure rating**

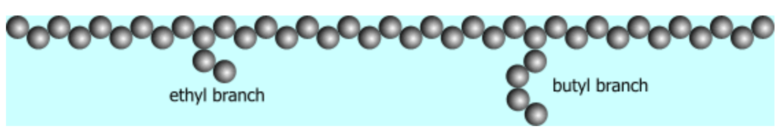
  ISO 12162 applies a minimum design coefficient divisor of 1.25 for MRS rated PE, but also advises the system designer to increase the design coefficient for service conditions, installation and handling. Using the minimum design coefficient alone takes only material variability into account; thus, it can be inadequate for field conditions. When compared to the additional design factor components that are incorporated into the North American 0.50 design factor for conventional thermoplastic materials, adding necessary design factor components for extrusion variability (0.05), handling and installation (0.20), unknown conditions (0.20), and adjusting MRS to 23°C (0.03), the design coefficient for PE100 in water service under field conditions should be at least 1.73 (0.58 DF) applied to the ISO MRS. (Note – an additional 0.20 component for surge pressure is included in the North American 0.50 DF.) ***When the ISO pressure rating is adjusted to the same temperature, and the ISO design coefficient includes components that address field application conditions that are already included in the North American DF, PE100 pipe pressure ratings are comparable to those for PE3408 pipe.***

Table 3 Comparative PE Pipe Pressure Ratings for Water at 23°C (73°F), psi

DR	7	7.3	9	11	13.5	15.5	17	21	26	32.5
PE100	279	266	209	167	134	116	105	84	67	53
PE3408	267	254	200	160	128	110	100	80	64	51
PE4710	336	320	252	202	161	139	126	101	81	64

How is High-Performance PE4710 Produced?

Polyethylene material performance is dependent on the molecular structure of the material. Polyethylene molecules are long carbon-carbon chains with side chain branches. Molecular weight, MW, is the total weight of the atoms in the molecule chain including side chain branches.



PE pipe materials are produced in polymer reactors. During production, molecule length (weight) will vary. The overall variation of molecular weight is statistically described as a molecular weight distribution, MWD. A typical MWD curve has a characteristic bell shape.

For many years, polyethylene reactor technology produced "unimodal" polyethylene materials, that is, the MWD curve is bell shaped with one peak. Over the past decade, however, new technology has developed for using two polymer reactors to produce polyethylene having a unique "bimodal" molecular weight distribution and enhanced physical properties.

Polyethylene properties are dependent on interrelationships among density, molecular weight, molecular weight distribution and the location and type of side chain branches on the PE molecule. Increasing density yields higher short-term strength, but reduces long-term strength; increasing molecular weight improves long-term strength, but reduces the ability to process into pipe and join the pipe by heat fusion. Broader MWD (a wider bell) improves processability, and lastly, the type and location of side chain branches on the PE molecule affects resistance to slow crack growth, the long-term failure mode for PE pipe.

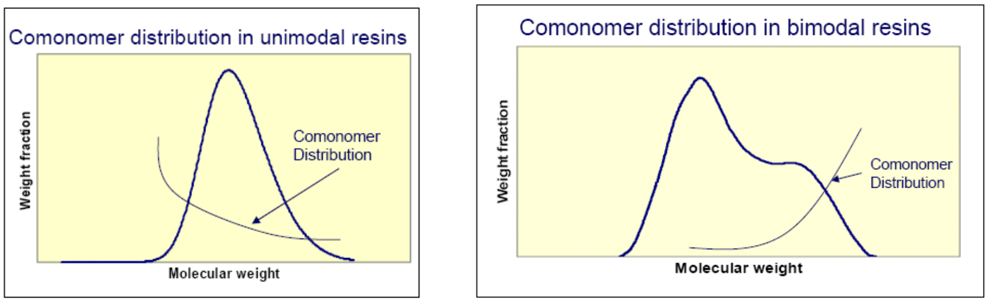


Figure 1 Unimodal and Bimodal Molecular Weight Distribution[1]

It was discovered that processing PE in a single reactor (unimodal technology) typically placed side chain branches on the shorter molecules where SCG resistance was least affected. A new technology for high-performance bimodal PE4710 materials uses two polymer reactors in series. With this new technology, side chain branches are typically placed on longer molecules, yielding huge gains in SCG resistance. Tenfold and higher improvements in SCG resistance can be realized. Further, with the new dual-reactor bimodal technology, density can be increased which increases tensile strength and chemical resistance; long-term strength is maintained and can even be significantly improved.

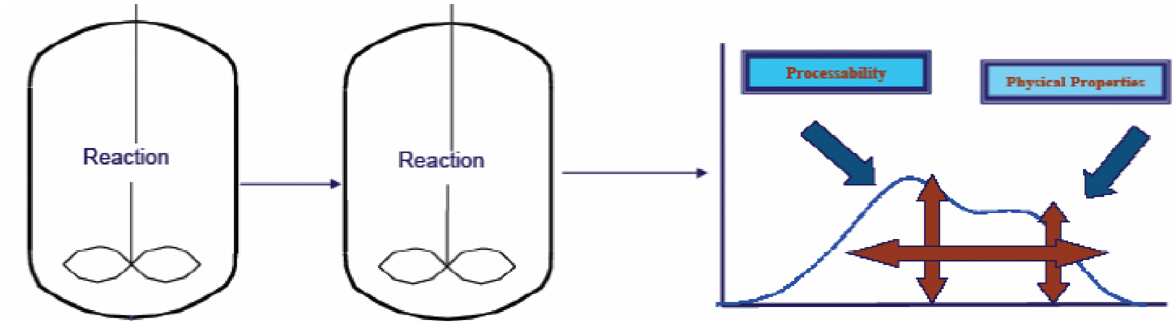
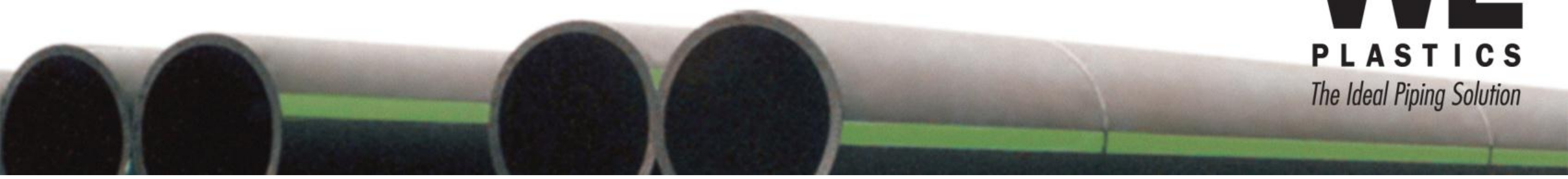


Figure 2 Dual Reactor Bi-Modal PE4710 Technology[1]



PLASTICS
The Ideal Piping Solution

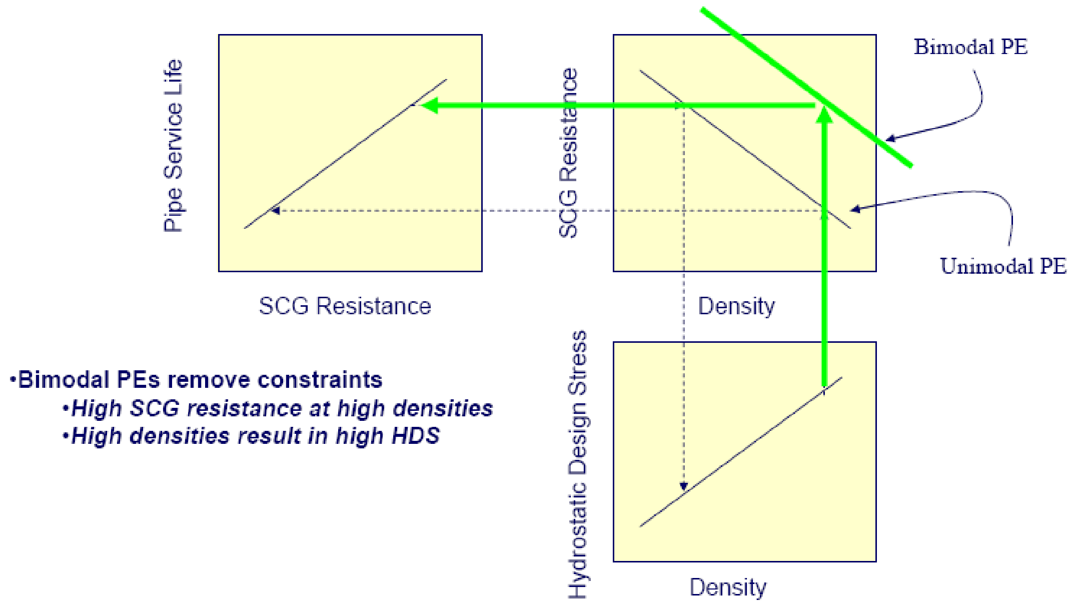


Figure 3 Unimodal and Bimodal Physical Property Relationships[1]

So What's Next?

PE4710 high-performance materials are the next evolution in polyethylene pipe – higher pressure ratings, increased flow capacity, and improved long-term performance – all without compromising traditional benefits of flexibility, leak-tight heat fusion joining, chemical resistance and ease of installation. With the establishment of performance characteristics and requirements for PE4710 materials, material and pipe specifications are being updated to include PE4710, and then codes for applications such as gas and water will be updated. Lastly, PE4710 products cannot be properly applied without technically sound, correct information. Education must be provided so that the industry may understand and know how to properly apply PE4710 products for maximum benefit. WL Plastics, resin suppliers, the Plastics Pipe Institute, standards writing organizations such as ASTM and AWWA, certifiers such as NSF, code bodies and other organizations are working to provide the benefits of high-performance PE4710 pipe to customers in North America and internationally.

ISO 9001:2008 Certified

CASPER PLANT: 2075 North Pyrite ● P. O. Box 1120 ● Mills, WY 82644 ● **Customer Service: 307-472-6000** ● Fax: 307-472-6200
CEDAR CITY PLANT: 4660 W. Highway 56 ● P. O. Box 627 ● Cedar City, UT 84721 ● **Customer Service: 435-867-8908** ● Fax: 435-865-2703
ELIZABETHTOWN PLANT: 2151 West Park Road ● Elizabethtown, KY 42702 ● **Customer Service: 270-765-1020** ● Fax: 270-765-1030
BOWIE PLANT: 1110 Old Wise Road ● P.O. Box 32 ● Bowie, TX 76230 ● **Customer Service: 940-872-8300** ● Fax: 940-872-8304
SNYDER PLANT: 2160 South Business 84 ● Snyder, TX 79549 ● **Customer Service: 325-574-6100**
CROSSFIELD PLANT: PO Box 860 ● 1030 Western Drive ● Crossfield, AB T0M 0S0 Canada ● **Customer Service: 403-946-0202** ● Fax: 403-946-0252
www.wlplastics.com

[1] Figures 1, 2 and 3 courtesy Lyondell Basell Chemical Company.