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PE100: Performance Plus

Steve D. Sandstrum*
INEOS Olefins & Polymers USA
Battleground Technical Center, La Porte, TX

ABSTRACT:

This is the third in a series of papers prepared at the request of the AGA-PMC to educate the US gas distribution industry on the history and benefits of PE100 polyethylene resins for gas piping applications. (1) In this paper, we will briefly review the origin of PE 100 and its performance history outside of the US as well as the standards by which PE 100 resins are classified. Typical physical properties for PE 100 will be explained and the relationship to pipe and fitting performance explored. The paper will conclude with specifics regarding enhanced performance of PE gas pipe produced from PE100 resin as it relates to higher pressure capability, improved slow crack growth resistance and enhanced resistance to rapid crack propagation.

INTRODUCTION:

The continuing expansion of applications for HDPE pipe has led to extensive research and development of higher performance polymers. Recognizing the needs of specific end uses such as natural gas distribution, resin companies in collaboration with pipe producers continue to develop materials which offer higher levels of performance as defined under internationally recognized

standards. "PE100" is one such evolution which has generated a significant amount of interest within recent years on an international level. This singular term has become synonymous with higher levels of performance in both water and gas HDPE pipe applications. Born within the ISO methodology, PE100 continues to be at the forefront of international focus for new piping applications. This paper shall provide a basic understanding of the nature of PE100 and shall focus specifically on the improved performance benefits it offers the gas distribution industry.

WHAT is PE100?

The term PE100 refers to the classification of polyethylene resins for piping applications using ISO 9080 and ISO 12162. (1) (2) ISO 9080 is one of the most widely recognized standard methodologies for regression analysis of piping materials in the world. .

(1) The first two paper in this series were: a) "What is PE100?" presented at the AGAPMC Winter Workshop, 1999 in New Orleans, LA, and b) "PE100 vs. PE3408: Can Someone Please Explain These?" presented at the AGA Operations Conference, 1999 in Cleveland, Ohio.

* Now with ISCO Industries LLC

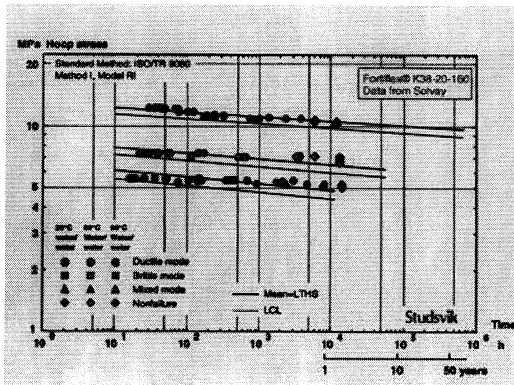


Figure I: Typical ISO TR9080 Regression Curves

The method is similar to that proposed in ASTM D2837. (3) Pipe specimens are placed on hydrostatic test in a controlled environment under specific conditions of stress and temperature. The specimens are monitored and data is gathered as pipe specimens fail over time. The data generated is then analyzed using the protocol presented in ISO 9080.

A typical set of ISO 9080 curves is shown in Figure I. The reader will note the similarities to the ASTM D2837 regression curves and the metric nomenclature.

**Table I
MRS Classifications and PE Designations**

LCL Range (MPa)	MRS Classification (Mpa)	PE Material Designation
3.15 – 3.99	3.15	PE31.5
4.00 – 4.99	4.0	PE40
5.00 – 6.29	5.0	PE50
6.30 – 7.99	6.3	PE63
8.00 – 9.99	8.0	PE80
10.00 – 11.19	10.0	PE100
11.20 – 12.49	11.2	-
12.50 – 13.99	12.5	-
14.00 – 15.99	14.0	-

Within ISO 9080, the stress regression curves are analyzed to determine the 50-year strength of

the material. The lower confidence limit (LCL) of the 50-year intercept generated using this technique is then categorized into one of a series of minimum recommended strengths (MRS) categories in megaPascals, or MPa as defined within ISO 12162.

A table of these LCL intercept values, their respective MRS classifications and subsequent PE designations is shown in Table I.

The fundamental technique by which these materials are analyzed is quite different from the procedure used in ASTM D2837 despite similarities in the methodology. Table II presents a summary of the fundamental differences between the two methods.

**Table II
Comparison of ISO TR9080 and ASTM D2837**

Property	ISO TR9080	ASTM D2837
Classification	MRS	HDB
Linearity	No assumption	Assumes linearity
Regression	All points combined	Individual temperatures
Coefficients	4	3
Extrapolation	50-year	100,000 hour
Intercept	97.5% LCL	Mean LTHS
Preferred Series	R20/R10	R20
Units	MPa	Psi

SIGNIFICANCE AND USE OF PE100:

The benefits of the PE100 classification come not only from its inherently higher performance capability as indicated by the higher MRS designation but also from the method by which it is utilized for various end-use applications within the ISO standards.

Since its introduction to the market place in the late 1980's, PE100 materials have been used extensively for both water and gas distribution

applications. For purposes of this discussion, we will focus primarily on the utilization of PE100 within gas distribution.

The prevailing standard for gas distribution on an international level is ISO 4437.(4) This standard places additional requirements on the PE100 classification which insure its higher, long-term performance capability as pipe. These supplemental requirements are summarized in Tables III and IV along with the requirements for PE80 materials. With the evolution of the EU, the usage of prEN standards have become more prevalent. The requirements presented in Table III and IV are also inherent to prEN 1555. (5)

Table III: PE100 vs. PE80 Compound Requirements

Quality	PE80	PE100
Density	≥ 930 kg/mm ³	≥ 930 kg/mm ³
Oxidation Induction Time	> 20 min @ 200 deg C	> 20 min @ 200 deg C
Melt Flow Rate	Δ max = 20% resin to pipe	Δ max = 20% resin to pipe
Volatile Content	≤ 350 mg/kg	≤ 350 mg/kg
Moisture Content	≤ 300 mg/kg	≤ 300 mg/kg
Carbon Content	2 - 2.5 %	2 - 2.5 %
Carbon Dispersion	≤ Grade 3	≤ Grade 3
Yellow Dispersion	≤ Grade 1	≤ Grade 1
Resistance to gas constituents	≥ 20 hr	≥ 20 hr
Slow Crack Growth @ 80 deg C	≥ 165 hr @ 0.80 Mpa	≥ 165 hr @ 0.92 MPa
Resistance to RCP in MPa at 0 deg C	FS ≥ MOP *1.5 Or S4 ≥ MOP/2.4	FS ≥ MOP *1.5 or S4 ≥ MOP/2.4

Note: The reader should be advised that all standards are under constant review and

revision. As such, at any one point in time small variances may exist between the information presented in Table III and IV and the current actual requirements presented in either ISO 4437 or prEN 1555. While every effort has been made here to be as accurate as possible, the reader is strongly encouraged to review each of these standards in their current version

Table IV: PE100 vs. PE80 Pipe Requirements

Quality	PE80	PE100
Tensile Strength	≥ 350 % Elongation @ Brk	≥ 350 % Elongation @ Brk
Hydrostatic Strength @ 20 deg C	≥ 100 hr @ 10 MPa	≥ 100 hr @ 12.4 MPa
Hydrostatic Strength @ 80 deg C	≥ 165 hr @ 4.6 MPa	≥ 165 hr @ 5.5 MPa
Hydrostatic Strength @ 80 deg C	≥ 1000 hr @ 4.0 Mpa	≥ 1000 hr @ 5.0 Mpa
Resistance to RCP in MPa at 0 deg C	FS ≥ MOP *1.5 Or S4 ≥ MOP/2.4	FS ≥ MOP *1.5 Or S4 ≥ MOP/2.4

While the performance requirements in these standards are very clear, a true appreciation of their meaning can only be developed when one considers the application of these requirements for a particular end-use such as the gas distribution application.

PE100: PERFORMANCE PLUS:

With respect to gas distribution, the benefits of PE100 polyethylene resins are three-fold. This new generation of materials provides for higher pressure capabilities while maintaining outstanding resistance to slow crack growth and rapid crack propagation. Some practical examples of how PE100 relates to the performance criteria of PE80 and PE3408 will follow.

Pressure Capability –

The design equation for gas distribution applications under the ISO protocol is very straightforward and is calculated as follows:

$$MOP = \frac{20 \times MRS}{C * (SDR -1)}$$

Where:

- MOP = maximum operating pressure (bars)
- MRS = minimum required strength (MPa)
- C = Overall design coefficient, ≥ 2.0
- SDR = Standard dimension ratio
= Outside diameter/wall thickness

The design equation for gas distribution under the ASTM system is modified to some degree to make it fit the English units. This equation is reprinted here from the AGA Plastic Pipe Manual. (6)

$$MAOP = \frac{2 \times (HDB) \times (F)}{(DR-1)}$$

Where:

- MAOP = max allowable operating pressure (psi)
- HDB = hydrostatic design basis (psi)
- F = design factor, 0.32 for gas
- DR = pipe dimension ratio
= outside diameter/wall thickness

Using these two equations, it is possible to compare the mathematical pressure capability for each series of pipe (PE100, PE80 and PE3408) under their respective standard protocols, namely ISO 4437 and ASTM D2513.

Table V compares the pressure designations for an SDR 11 pipe produced from the three different classifications of material and placed into service under both of the prevailing protocols, ISO 4437 or ASTM D2513. From this, we see that the end results are quite interesting. Specifically:

- a) The PE100 material allows for a 25% increase in the MOP under the ISO protocol as compared to PE80.
- b) The ISO and ASTM pressure equations are essentially the same but the results are quite different as it relates to pressure rating.
- c) The differences lie in the application of the design factor and how it is stated, the units or measurement and the limitations placed on the application.

One should also bear in mind that in the United States, CFR Title 49, Part 192.121 limits the MAOP for polyethylene to 100 psi. This is currently under study for increase to 125 psi. Similarly, the service factor of 0.32 is being evaluated for increase to 0.40. These two factors would significantly affect the range of application for any materials used in accordance with ASTM D2513 and certainly influence the comparison presented in Table V.

Table V: PE100 vs. PE80 vs PE3408 Pressure Rating

Design Aspect	PE100	PE80	PE3408
Prevailing Standard	ISO 4437	ISO 4437	ASTM D2513
MRS (Mpa)	10	8	
HDB (psi)	-	-	1600
Service Coefficient, C	2	2	-
Design Factor, F	-	-	0.32
Pipe SDR	11	11	11
MOP, bars	10	8	-
MAOP, psi	-	-	102
MAOP equivalent	145*	116*	-
MOP equivalent	-	-	7.0 *

*Note: The MAOP and MOP equivalents shown in Table V are mathematical conversions of the MOP and MAOP values shown in the table, respectively. These are provided for purposes of reference and comparison only and

their presentation in this table should not be considered as a qualification or approval for use in gas distribution under the opposing standard protocol.

Resistance to Slow Crack Growth –

Both ISO 4437 and prEN 1555 require that PE100 materials demonstrate a higher level of performance relative to slow crack growth. The PE100 materials must meet the 165 hour minimum at a stress level of 9.2 bars when tested in accordance with ISO TR13479, the notched hydrostatic pipe test. (7) Similarly, PE80 materials are required to meet the 165 hour limit at a lower 8 bar stress.

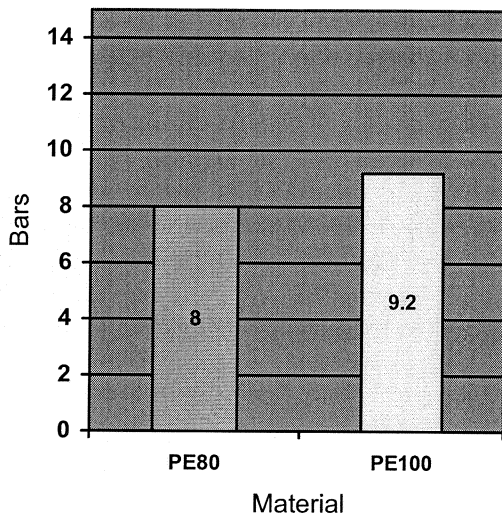


Figure II: Resistance to SCG for PE80 and PE100

Notched pipe testing is not required in ASTM D2513. However, ASTM D2513 does require that materials used for natural gas distribution must exceed specific requirements for either bent strip ESCR per ASTM D1693 or PENT testing per ASTM (8) (9)

In the case of bent strip testing, materials used in natural gas distribution piping must exhibit an F(0) value in excess of 600 hours when testing in accordance with condition C of ASTM D1693. Alternatively, the material may be

qualified for use in natural gas distribution piping if it exhibits a PENT value in excess of 100 hours when tested in accordance with ASTM F1473.

Resistance to slow crack growth of gas piping materials under the various standards is summarized in Table VI.

Table VI: Requirements for Resistance to Slow Crack Growth

Material	Standard	Threshold Value
PE100	ISO 4437	≥ 165 hours @ 9.2 Bar
PE80	ISO 4437	≥ 165 hours @ 8.0 Bar
PE3408	ASTM D1693 Or ASTM F1473	≥ 600 hours ≥ 100 hours

Resistance to slow crack growth has been the subject of a great deal of research over the years. While the methods for determining the slow crack growth resistance of pipe materials do differ based on the prevailing standards in place, all three are proposed as a means by which to characterize a material's ability to resist failure in response to low level, long term stress. From the information presented in Table VI, we see that the requirements placed on PE100 provide for a much higher level of SCG resistance.

Resistance to Rapid Crack Propagation –

The potential for rapid crack propagation (RCP) has been well-researched and well-documented in the literature. RCP is a phenomenon where sudden impact to a pressurized pipe results in the formation of a longitudinal through-wall crack that travels along the pipe at very high speeds. It has been recognized that as the operating pressure for a

gas conveying system increases, the potential for failure via RCP increases. (10)(11)(12)

ISO 4437 requires that PE100 must meet the prevailing requirements for resistance to rapid crack propagation. To the gas utility this equates to potentially higher operating pressures at larger diameters while minimizing the potential for failure due to RCP.

Table VII: RCP Resistance of Polyethylene Gas Pipe Required in ISO 4437

Property	Full-Scale	S4
Size of Specimen	≥ 250 mm	≥ 15 mm
Test Temperature	0 degree C	0 degree C
Test Requirement	$P_c > MOP * 1.5$	$P_c > MOP/2.4$

As one can see from Table VII, the critical pressure is a function of the material's MOP. That is, the higher the MOP for a given material, the higher the critical pressure, P_c , will become. This aspect of rapid crack propagation has traditionally limited the use of polyethylene to lower pressure gas applications. The greater toughness and durability of the PE100 materials have allowed their use at higher pressures up to 10 bar for gas due to its quantifiable resistance to RCP.

It should be noted that the ASTM system does not currently address the potential for RCP within D2513. However, federal regulation of the maximum allowable operating pressure and the design factor is felt to accommodate concerns relating to the RCP phenomenon.

At this time, the MAOP for polyethylene in gas distribution within the United States is limited to 100 psi and the design factor is established at 0.32. Continued improvement in polyethylene resins and the excellent service history of HDPE within the US gas distribution industry have resulted in consideration of a

higher level MAOP and design factor for these applications.

PUTTING IT ALL TOGETHER:

It is reasonable to assume that long-term strength, resistance to slow crack growth and resistance to rapid crack propagation are essential design criteria of an HDPE gas distribution system. Figure III combines these three aspects of system design into a dimensional array. From this graphic, we see that the evolution of PE100 clearly provides the potential for a much broader range of usage in HDPE gas distribution systems under the ISO design protocol.

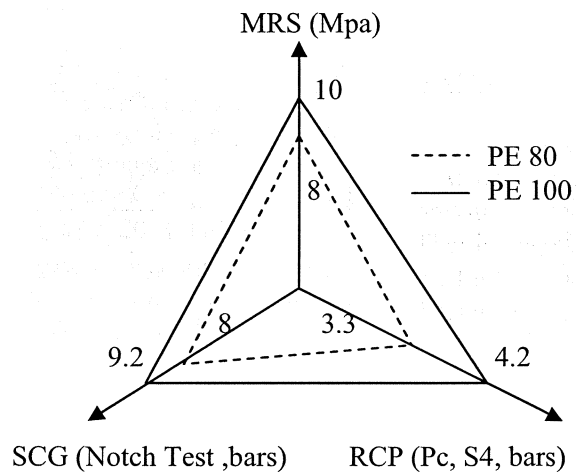


Figure III: PE100 vs. PE80 SDR 11 Performance Comparison

CONCLUSION:

This discussion has focused on the development and evolution of the PE100 quality of polyethylene pipe resins and its potential impact on the gas distribution application. As a result of this discussion, the reader should have gathered a fundamental understanding of the nature of PE100 and the benefits associated with its use. These unique materials offer a higher level of performance as evidenced by:

- higher pressure capability
- increased resistance to SCG
- and, improved resistance to RCP

as required under the ISO standards systems. From the information presented here, it should be relatively apparent why these materials are quickly becoming the international standard for polyethylene gas piping applications around the world.

REFERENCES:

- (1) ISO 9080, "*Plastics Piping and Ducting Systems Determination of Long-Term Hydrostatic Strength of Thermoplastics Materials in Pipe Form by Extrapolation*", International Organization for Standardization.
- (2) ISO 12162, "*Thermoplastics Materials for Pipes and Fittings for Pressure Applications – Classification and Designation – Overall Service (Design) Coefficient*", International Organization for Standardization.
- (3) ASTM D2837, "*Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials*", American Society for Testing and Materials.
- (4) ISO TR4437, "*Buried Polyethylene (PE) Pipes for Supply of Gaseous Fuels – Metric Series – Specifications*", International Organization for Standardization.
- (5) PrEN 1555, "*Plastics Piping Systems for the Supply of Gaseous Fuels – Polyethylene (PE)*", Comite European de Normalization (CEN).
- (6) Plastic Pipe Manual for Gas Service, American Gas Association, Arlington, VA, 1994.
- (7) ISO 13479, "*Polyolefin Pipes for the Conveyance of Fluids – Determination of Resistance to Crack Propagation – Test Method for Slow Crack Growth on Notched Pipes (notch test)*", International Organization for Standardization.
- (8) ASTM D1693, "*Standard Test Method for Environmental Stress-Cracking of Ethylene Plastics*", American Society for Testing and Materials, West Conshohocken, PA.
- (9) ASTM F1473, "*Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins*", American Society for Testing and Materials, West Conshohocken, PA.
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