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PE100 vs. PE3408: Can Someone Please Explain These?

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ABSTRACT:

This is the second 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. (I) In this paper, we will explore the fundamental differences between a PE100 and a PE3408 polyethylene resin for gas distribution pipe production. Inherent in this discussion will be a brief overview of the standards and protocol by which both materials are defined and how these relate to the usage of each material in gas distribution applications. The discussion shall conclude with a direct comparison of typical PE3408 to PE100 on the basis of the physical properties of the two and the performance guidelines and limitations of both. From this paper the reader should develop a clear understanding of the differences and similarities of these two materials and how they are utilized in the gas distribution industry.

INTRODUCTION:

The continuing expansion of applications for HDPE pipe has led to extensive research and development of higher performance

polymers. Recognizing the performance needs of specific end uses such as natural gas distribution, resin companies in collaboration with pipe manufacturers continue to develop materials which offer a higher level of performance as designed under internationally recognized standards. In the United States, this evolution has culminated in a category of HDPE piping that is referred to as PE3408. Since its introduction in the late 1970's, this classification of HDPE pipe products has been recognized for its higher level of pressure capability as defined under the regulations and standards endemic to the United States such as ASTM. On a more global scale, PE100 has rapidly become a mainstay within the international gas distribution community owing to the enhanced performance capabilities it affords. These qualities are more readily apparent under the ISO and CEN standards systems. While the two designations, PE3408 and PE 100, sound very similar; the breadth of qualities that they each represent are (1) The other two papers in this series are: a) "What is PE100? ", presented at the AGA-PMC Winter Workshop, 1999 in New Orleans, LA, and b) "PE100: Performance Plus ", to be presented at the 1999 International Plastic Fuel Gas Pipe Symposium in New Orleans, LA.

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considerably different. This paper is offered to provide a basic understanding of the two designations, the performance attributes they represent and the relationship of the two terms to each other.

WHAT IS PE3408?

The term PE3408 is widely recognized within the North American gas distribution industry. Since its inception, the term has become synonymous with a higher level of performance in the demanding gas distribution applications. But, what does the term PE3408 actually mean?

The PE3408 terminology has its roots in ASTM D2513, section 3.6. (1) This standard requires that any plastic pipe that is to be used in gas distribution must have a “standard thermoplastic designated code”. The standard thermoplastic code shall consist of an abbreviation for the type of plastic followed by Arabic numerals, which describe the short-term properties for that material in accordance with applicable ASTM standards. The final two numerals in the term refer to the hydrostatic design stress for that material in units of 100 psi with any decimal figures dropped.

P	PE designation refers to
E	polyethylene
3	Density cell class 3 per D3350
4	SCG cell class 4 per D3350
0	800 psi hydrostatic design stress
8	for water at 73.4 F

Figure I: The Definition of PE3408

As shown in Figure I, the term PE3408 clearly identifies the piping compound as a polyethylene grade P34 with a density cell

class of 3 in accordance with D3350, a slow crack growth cell class of 4 also in accordance with D3350, and an 800 psi maximum hydrostatic design stress at 73.4 ° F as recommended by the Plastics Pipe Institute. (2)

Of particular importance is the determination of the hydrostatic design stress in accordance with ASTM D2837. (3) This standard is utilized within North America to determine the long-term pressure capability of plastics for piping applications. The categorization established in ASTM D2837 is based on a regression analysis to 100,000 hours and is presented in Table I.

**Table I
Hydrostatic Design Categories from
ASTM D2837**

Range of LTHS, Psi	Hydrostatic Design Basis, psi
380 to 470	400
480 to 590	500
600 to 750	630
760 to 950	800
960 to 1190	1000
1200 to 1520	1250
1530 to 1910	1600
1920 to 2390	2000
2400 to 3010	2500

The combination of these specific properties provides the gas distribution utility the assurance of the material’s ability to sustain higher operating pressures than its PE3406 predecessor when utilized in accordance with the guidelines established by the US Department of Transportation (USDOT) Code of Federal Regulations, 49 CFR Part 192.121.(4) This regulation establishes a service factor for gas distribution of 0.32. When this service factor is taken into consideration the pressure capability of PE3408 versus a PE3406 can be readily demonstrated as shown in Figure II.

$$P = 2S \frac{t}{(D-t)} \times 0.32$$

Where: P = design pressure, psi
 S = Long term hydrostatic design stress, psi
 D = Outside diameter, in.
 t = minimum wall, in

For PE3406 12" IPS SDR 17

P = 50 psi

For PE3408 12" IPS SDR 17

P = 64 psi

Figure II: PE3408 vs. PE2406

Taken altogether, the term PE3408 provides for higher pressure capability while requiring the same level of slow crack resistance as specified for its predecessor, the PE3406.

WHAT IS PE100?

The same research and development has occurred on a more global level under a different set of standards and test methods. These developments have culminated in the introduction and wide-spread acceptance of PE100 as a higher level of performance for HDPE pipe applications.

The term PE100 refers to the classification of polyethylene resin for piping applications using ISO 9080 and ISO 12162. (5)(6) ISO 9080 is one of the most widely recognized standard methodologies for regression analysis of piping materials in the world. The method is similar to that proposed in ASTM D2837. 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.

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 is then categorized into one of a series of minimum recommended strengths (MRS) categories in megaPascals, or mPa, as defined in ISO 12162. A table of these LCL intercept values, their respective MRS classification and subsequent PE designations is shown in Table III.

**Table III
 MRS Classifications and PE Designations**

LCL Range (mPa)	MRS Classification (mPa)	PE Material Designation
3.15 – 3.99	3.2	PE32
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	-

The prevailing standard for gas distribution on an international level is ISO 4437. (7) This standard places additional requirements on the PE100 classification which insure its higher, long-term performance capability as pipe.

SO WHAT IS THE DIFFERENCE IN BETWEEN PE100 AND PE3408?

The terms PE100 and PE3408 are similar in that both reference an extrapolation of the hydrostatic performance of polyethylene pipe under standardized conditions: the PE100 under ISO 9080 and PE3408 under ASTM D2837. Then how do the terms differ?

The designations differ in two respects. First, the exact method by which the long term strength of each material is established

is different. Secondly, the manner in which each of these materials is utilized in accordance with the prevailing gas distribution standard within each system is also different. Each of these aspects will be discussed in some detail as follows.

Establishing the Long Term Strength ---

The comparison of the ISO 9080 and ASTM D2837 regression methods has been the subject of extensive previous publication.(8)(9) Suffice to say, both methods deal with the placement of pipe specimens on test at specified conditions of stress and temperature. Data is collected as pipe specimens fail and the data is then analyzed using a methodology specific to each standard.

The two methods differ specifically in their treatment of the pipe failure data. Both methods utilize a basic regression equation to project the service life of the material being analyzed. The ASTM D2837 method establishes a long-term hydrostatic strength (LTHS) at 100,000 hours based on the collection and regression analysis of 10,000 hours of pipe failure data. ISO 9080 uses the same 10,000 hours of data to project a service life at 50 years. The fundamental differences between the two methods are summarized in Table IV.

**Table IV
Comparison of ISO 9080 and
ASTM D2837**

Property	ISO 9080	ASTM D2837
Classification	MRS	HDB
Linearity	No assumption	Assumes linearity
Regression Method	All points combined	Individual temperatures
Coefficients	4	3
Extrapolation	50-year	100,000 hours
Intercept	97.5 % LCL	Mean LTHS
Preferred Series	R20/R10	R20
Units	MPpa	Psi

The net effect of this difference in regression analysis and the subsequent categorization of the intercepts may be seen in Figure III. Here we see that the ISO regression extends well beyond the 100,000 hour intercept established by ASTM D22837.

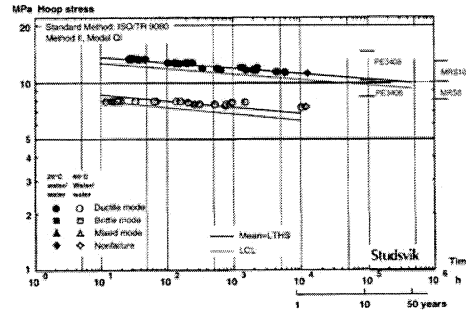


Figure III: ISO 9080 Regression Curve for a PE3408

The reader will note that Figure III depicts two data sets, the top one at 20 deg F and the lower one at 60 deg F. Also note that the LCL regression is shown as the lower “shadow” line below each data set.

Utilization of Each Material ---

As previously indicated, the differences between the PE3408 and PE100 designation are not limited to the manner by which each stress rating is determined. In addition to this, specifications exist within each standard system which place supplementary requirements on each respective material. Further, the systems are slightly different in the treatment of the pressure rating to be determined for gas distribution applications.

ASTM D2513 is the prevailing specification for plastic piping in gas distribution within North America. This rigorous standard places additional requirements on the PE3408 material to qualify it for use in these applications. These requirements are summarized in Table V.

Table V: PE3408 Requirements in ASTM D2513

Property	PE3408 Requirement
Resin	
HDB @ 73 deg F	1600 psi
Validation @ 73 deg	
HDB @ 140 deg F	800 psi or 1000 psi
Validation @ Elevated temperature HDB	
Substantiation of Linearity out to 50 yrs.	Linearity out to 438,000 hour (50 years)
Chemical Resistance	< 0.5% weight gain
Density	0.941-0.955 gr/cc
Melt Index	< 0.15 gr/10 min
Flex Modulus	3000 – 4000 psi
ESCR	F(20) > 600 hours
PENT	> 100 hours
Thermal Stability	Min induction temp > 220 C
Pipe	
Dimensionals	Various
Validation of HDB at 73 deg F	1600 psi
Sustained pressure test	> 1000 hrs @ 1600 psi
Squeeze-off testing	> 1000 hrs @ 1600 psi
Burst Strength	Ductile failures only
Apparent Ring Tensile	> 2520 psi
Outside Storage Stability	> 2 years

On a more global level, the prevailing standard for gas distribution is ISO 4437. This standard places additional requirements on the PE100 classification which assures its long-term performance capability as pipe. These supplemental requirements are summarized in Table VI. With the evolution of the EU, the usage of prEN standards have become more prevalent. The requirements presented in Table VI are also inherent to PrEN 1555.(10)

Table VI: PE100 Requirements in ISO 4437

Property	PE100 Requirement
Resin	
MRS @ 20 deg C	10
Density	≥ 930 kg/mm ³
Oxidation Induction Time	> 20 min @ 200 deg C
Melt Flow Rate	Delta max = 20% resin to pipe
Volatile Content	≤ 350 mg/kg
Moisture Content	≤ 300 mg/kg
Carbon Content	2 – 2.5 %
Carbon Dispersion	≤ Grade 3
Resistance to gas constituents	≥ 20 hours
Slow Crack Growth @ 80 deg C	≥ 165 hours @ 0.92 mPa
Resistance to RCP at 0 deg C	FS ≥ MOP * 1.5 Or S4 ≥ MOP/2.4
Pipe	
Dimensionals	Various
Tensile Strength	≥ 350 % elongation at break
Hydrostatic Strength at 20 deg C	≥ 100 hours @ 12.4 mPa
Hydrostatic Strength at 80 deg C	≥ 165 hours @ 5.5 mPa
Hydrostatic Strength at 80 deg C	≥ 1000 hours @ 5.0 mPa
Resistance to RCP in mPa at 0 deg C	FS ≥ MOP * 1.5 Or S4 ≥ MOP/2.4

From an analysis of the information presented in Tables V and VI, we see that the requirements for the two types of materials designations are different and yet the same. The ASTM D2513 standards require substantiation of the linearity of the material's hydrostatic performance out to 50 years and verification of the elevated temperature performance.

ISO 4437, on the other hand, recognizes the long-term regression analysis inherent to the ISO 9080 protocol and, as such, does not delve into substantiation of linearity. ISO 4437 does, however, place a requirement for resistance to rapid crack propagation (RCP).

ASTM D2513 makes no mention of RCP at all.

Practical Aspects of PE100 and PE3408:

Pressure Capability ---

Given the material requirements outlined within each one of the standards system, one would assume substantial differences in the manner in which these materials are used in gas distribution applications.

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

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

Where:

- MOP = max operating pressure (bars)
- MRS = min required strength (bars)
- 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.

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

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

Table VII compares the pressure designation for a 12" SDR 11 pipe placed into service under both of these protocols.

From Table VII, we see that the end result is quite different. The two equations are essentially the same. 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.

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.

Table VII: PE100 vs. PE3408 Pressure Rating

Design Aspect	PE100	PE3408
MRS (Mpa)	10	
HDB (psi)		1600
Service Coefficient, C	2	
Design Factor, F		0.32
Pipe SDR	11	11
MOP, bars	10	
MAOP, psi		102
MAOP equivalent	145*	
MOP equivalent		7.0 *

*Note: The MAOP and MOP equivalent shown in Table VII 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.

Slow Crack Growth ---

Both ISO 4437 and prEN 1555 require that PE100 materials demonstrate a higher level of performance relative to slow crack

growth. As indicated in the previous comparison, 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. (11) Similarly, PE80 materials are required to meet the 165 hour limit at a lower 8 bar stress. Notched pipe testing is not required in ASTM D2513.

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. (12)(13)(14)

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 VIII: 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 VIII, 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.

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.

Currently, 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.

CONCLUSION:

This discussion has focused on the comparison of the two terms, PE3408 and PE100. As a result of this discussion, the reader should have gathered a fundamental understanding of:

- the nature of these two terms
- how they relate to each other
- and, how they are utilized within their respective standards systems as it relates to gas distribution.

From this discussion, we have also determined differences between the two standards systems as they relate to:

- the long term regression analysis methods
- magnitude of the design factor for gas distribution
- and, the regulation of the maximum pressure capability for gas distribution.

While the methods by which we evaluate these materials are somewhat different, the philosophy by which each term is applied within its respective standards system is essentially the same. The end result under either standards system, ASTM or ISO, is substantiation of higher levels of performance in HDPE gas distribution piping. Clearly, as the gas industry continues to globalize, the need to understand each of these terms and how they are utilized will only expand.

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