

Can PE Gas Pipe *Really* Replace Large Diameter Cast Iron and Steel Gas Pipe?

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1. The State of the Industry

In the current state of the gas industry, an interesting dynamic exists, being anchored in both the old and the new and generating as much concern as excitement. The gas distribution industry “lives” in the past, the present and the future all at the same time. In the past are aging metallic systems, which in most ways have been quite successful for all pipe sizes. The present is represented by polyethylene (PE) materials, both PE2406 and PE3408 with outstanding field performance in pipe diameters less than 12” (predominantly), and the continued use of steel materials in larger diameters. In the future are advanced plastic materials, such as PE4710, with step-change improvements in material properties, and large diameter implications. All of these materials are all “in play” at the same time for utility engineers, who must balance application, performance and the operating environment.

These are the boundaries of the latest gas frontier, system reliability, regulatory compliance, return on investment and the safe application of advancing technologies. System design must be for the future, while maintenance and operations must be for the present and the past. All must be safely and efficiently integrated and operated, while maintaining compliance with the ever increasing regulatory demands. “Future” materials generate excitement in the potential to upgrade aging systems and reduce maintenance costs. However, the over-riding concern for system safety and reliability on the part of utilities and regulatory agencies effectively throttles the pace of change.

2. Respect for Lessons Learned

Why aren't material advancements rapidly incorporated into systems by utilities and codes by regulatory agencies? The real answer is that the gas industry has learned some hard lessons regarding the rapid and widespread use of “new” materials over the years, particularly in the earliest years of new plastic materials. With the charge of safely transporting natural gas, caution is warranted regarding the short and long term performance of installed materials. Leaders in both industry and regulatory agencies have had first hand experience in the ramifications of installing materials with inferior performance.

Regulatory agencies, saddled with oversight of a varied and complex array of gas distribution networks, consider “yesterday” and “today”, attempting to ensure the capture and incorporation of lessons learned in system design and operation. There is a hesitancy to embrace the latest PE materials and enable operation at increased levels of performance without establishing some confidence in the ability to properly install and operate at higher levels of performance. “Special permit” or “waiver” installations are the vehicle through which regulatory agencies establish confidence in the safe installation and operation of new materials. Even with use of the special permit process, the overall history of good and bad experiences still creates apprehension and process delays. In particular, large diameter PE applications raise concerns about operational safety and reliability, with questions regarding material properties of pressure ratings, slow crack growth resistance (SCG) and rapid crack propagation (RCP).

With these concerns in mind, the question is will the “future” materials allow us to meet *all* the demands. Can PE4710 pipe really enable the safe replacement of large diameter cast iron and steel gas pipe? We will answer the question by exploring the critical factors that affect the safety and performance of large diameter PE gas pipe.

2. Key Design Considerations

The key to making it all work together is in understanding clearly and separating the critical factors of designing and operating for higher efficiency and performance. The continued safe operation of existing systems with aging components requires knowledge of material limitations and safe operating boundaries. The obvious key is to not operate the system in such a way as to exceed the capability of the materials in service. The design, construction and operation of safe and reliable systems for the future require the same basic knowledge; know your “safe operating window” and operate within it. Utility engineers need to identify the environmental limits (operating temperature and pressure ranges) associated with their distribution system. These boundaries, along with any specific handling, storage or construction procedure considerations, all combined establish the “safe operating window.” System design needs must first address material limitations, and then pressure rating criteria and design factors can be applied to ensure both safety and compliance.

While knowing the material and system boundaries is critical for system safety and reliability, proceeding within federal and state codes is required by law. 49 CFR Part 192 defines pressure rating criteria, maximum allowable operating pressure (MAOP) and diameter ranges. The present design factor used in the pressure rating formula is 0.32. The MAOP for PE materials up to 12 inch diameter is 125 psig. Based upon the current American Society of Testing and Materials (ASTM) reference, the MAOP of PE materials from 14 inch to 24 inch diameter is 100 psig. The basis and appropriateness of these design and operating limitations themselves are out-of-scope in this paper and recognized simply as requirements and further boundaries.

3. Material Properties

The current high density bimodal PE pipe materials employed at PSE&G have a material designation code of PE4710. This is the highest level of new PE material designations that have recently been created in ASTM Standards; designed to enable the more accurate differentiation of materials and varying levels of performance. These materials are listed in the Plastics Pipe Institute (PPI) TR-4 with 1000 psi HDS at 73F (23C). PE 4710 materials exhibit a high level of performance in all three critical areas of material consideration (material limitations): pressure capability, resistance to SCG, and RCP. These particular material properties have significantly improved over previous generation PE materials (material designations of PE 2406 and PE 3408). Discussion on each of these critical properties shall demonstrate how PE4710 materials far exceed established requirements for performance and open the door for large diameter and high capacity applications.

4. Pressure Capability

As determined in DOT regulations (49 CFR Part 192), the maximum operation pressure (MOP) of a PE gas pipe is determined by equation (1)

$$MOP = \frac{2 \times HDB \times F}{SDR - 1} \quad (1)$$

The operation pressure of a PE gas pipe must be below the MOP value calculated by equation (1) and the MAOP regulated by DOT. The MAOP of PE gas pipe was 100 psig, until recently being increased to 125 psig for sizes up to 12”. Currently regulations require the use of 0.32 design factor for PE gas pipe. All PE gas pipe, regardless of traditional PE2406 and PE3408 or the most advanced high performance PE4710 materials, must employ the 0.32 design factor in establishing the pipe MOP.

The intended application of large diameter PE4710 gas pipe at PSE&G is in replacement of aging metallic systems operating at 60 psig and below. These operating pressures are below the calculated MOP (Equation (1)) and the imposed MAOP as defined in 49 CFR Part 192. Note that Equation (1) is independent of pipe diameter. For a given PE material, the pressure capability is determined by standard dimension ratio (SDR) not by pipe diameter. There is no pressure rating difference between small diameter pipe and large diameter pipe if the SDR is same.

It is worth pointing out that PE gas pipe has never failed in a ductile mode during the near half century of application, due to the excessive internal pressure. However, it has been observed that PE gas pipe can fail in SCG mode at very low stress levels.

5. Resistance to Slow Crack Growth

SCG resistance is a measure of long term material performance against brittle failure. To demonstrate the relative change in material performance, one only need look at the minimum requirements in ASTM standards for SCG resistance for PE gas pipe. As industry standards were updated to reflect advancements in material properties, cell classifications were updated to reflect the changes in materials. The second numeric digit in the material designation code of PE 4710 is the cell classification for SCG resistance. To have a SCG cell classification of 7 requires the material to meet a minimum Pennsylvania Notch Test (PENT) result of 500 hours. An SCG cell classification of 6 requires the material to meet a minimum PENT result of 100 hours. Previous material designations of PE 2406 or PE 3408 used at PSE&G would now have a SCG cell designation of PE 2606 and PE 3608 respectively by meeting the 100 hour minimum PENT. In terms of relative capability, the latest PE 4710 materials are required to demonstrate a 400% increase in material performance in terms of SCG resistance!

Table 1 - Material Properties

Material Designation	PENT (hrs)		HDB
	SCG 6	SCG 7	
2406*	100	---	1250
2606	100	---	1250
3408*	100	---	1600
3608	100	---	1600
4710	---	500	1600
* Previous Material Designations			

It is well accepted that a higher PENT material will perform better against SCG failure than a lower PENT material for the same pipe dimensions and same operation conditions. However, pipe may be scratched during pipe shipment or/and installation. It may also be subjected to third party damage. The pipe geometry will be a factor in determining the SCG failure process. PE gas pipe is pressure rated based on SDR and the absolute wall thickness is not relevant. However, SCG resistance is controlled by stress intensities which in turn are determined by applied stress and real notch depth. A large diameter pipe will have thicker wall thickness than a smaller diameter pipe with the same SDR. With the same percentage of notch depth, a larger diameter pipe has a deeper notch, with greater stress intensity. A major regulatory concern is that large diameter pipe will fail faster as SCG will be accelerated. This concern is real and valid. Let's look at this aspect of performance and concern more closely.

First, let us investigate the thickness effect in PENT testing and results. In order to validate PENT performance across different pipe sizes for a given material, the PENT specimens would need to be varied

to mimic the various wall thicknesses of the pipes. The notch depth must also be changed accordingly in order to keep the same stress intensity and test condition.. The PENT test uses a 2.4 MPa stress at 80C. The standard PENT specimen of 25mm x 10mm with 3.5mm main notch has a stress intensity of 0.468 MPa m^{1/2}. Table 2 illustrates the correlation between thickness, notch and notch percentage, as well as the approximate equivalent pipe diameter (roughly SDR 11) the test would represent. As shown, as specimen thickness increases, the absolute notch depth increases. Notice however that the percentage of notch depth (in relation to the overall specimen thickness) decreases in order to generate the same failure time. If for example the specimen thickness is reduced from 10mm to 5mm, the notch depth must be decreased to 2.28mm, but the percentage of notch depth actually increased to 46%. Similarly, if the specimen thickness is increased to 20mm, the notch depth must be increased to 5.20mm, but the percentage of notch depth actually decreased to 26%.

Table 2. Notch Depth as a Function of Specimen Thickness for PENT Test

PENT (F14730 Notch Depth)				
Sample Thickness (mm)	Notch Depth (mm)	% Depth	Equivalent Pipe Size	SDR (approx.)
5	2.28	46%	2"	11
10	3.5	35%	4"	11
15	4.48	30%	6"	11
20	5.2	26%	8"	11

For a rough comparison to SDR 11 pipe, a 2" outside diameter pipe with 2.28mm notch and 46% of notch depth, a 4" OD pipe with 3.5mm notch and 35% notch depth, and a 8" OD pipe with 5.2mm and 26% notch depth would have the same SCG failure time. However, if we keep the same 35% of notch depth, the 8" pipe would fail first, followed by the 4" pipe and then the 2" pipe due to the increased stress intensity.

It is generally accepted for PE pressure pipe that the scratched pipe with 10% of scratch depth would have an equivalent field performance to the un-scratched pipe within the design limit. This is true if the pipe diameters do not change much. From Table 2, the standard PENT test is roughly for nominal 4" pipe. It is not a pipe geometry issue for pipe sizes smaller than 4" as the stress intensity is lower. From 4" to 12", the pipe diameter increases by a factor of 3. The standard PENT specimen is a reasonable average size representation for pipe diameters from 1/2" to 12".

The SCG resistance as measured by PENT is determined by Equation (2)

$$PENT = A \times K^{-m} \times e^{\frac{Q}{RT}} \quad (2)$$

Where m is about 4. The stress intensity, K, is controlled by stresses and notch depth. For the same PE gas pipe material with the same stress but different wall thickness, Equation (2) becomes Equation (3).

$$\left(\frac{a_1}{a_2}\right)^2 = \frac{PENT_2}{PENT_1} \quad (3)$$

To keep the same notch depth in percentage such as 10%, the larger diameter pipe with increased wall thickness would have greater absolute notch depth and the PENT time to failure (hours) would be shorter. For every 1-fold increase of thickness, the PENT time would be shortened by a factor of 4. In order to

ensure the same field performance, there are two options. One is to reduce the notch percentage in half. The absolute notch depth would be same and therefore the PENT would be same. This is the case for using the same existing material for large diameter pipe. You may not be able to expand the existing materials to larger pipe by keeping the same design criterion for maximum allowable notch percentage. Another option is to improve the materials PENT performance by a factor of 4 to compensate for the increase in absolute notch depth and associated stress intensity.

If PE3608 (formally PE3408) with 100h PENT gives satisfactory field performance against SCG failure up to 12" SDR 11 pipe with a 10% scratch, the maximum scratch must be lowered to 5% for 24" SDR 11 pipe in order to have the same field SCG resistance. If we want to keep the 10% notch, the PENT hours of the PE3608 must be improved to 400h. PE4710 (formally also PE3408) pipe with a minimum PENT requirement of 500h, in a diameter of 24", should have better SCG resistance than a PE3608 pipe in a diameters of 12", with the same % of notch.

Table 3. Required PENT Performance for a 10% Scratch

SCG Comparison				
Pipe Material	Pipe Size	SDR	Scratch Depth	Required PENT
PE3608	12"	11	10%	100h
PE3608	24"	11	5%	100h
PE3608	24"	11	10%	400h
PE4710	24"	11	10%	500h

To compare two PE gas pipe materials of PE3608 and PE4710 with the same 0.32 design factor, Equation (3) becomes Equation (4).

$$(a_{PE3608})^2 \times PENT_{PE3608} = (a_{PE4710})^2 \times PENT_{PE4710} \quad (4)$$

Equation (4) can be used to estimate the desired PENT hours for large diameter PE4710 pipe based on PE3608 properties. Equation (4) is useful when we consider using large diameter PE4710. We must either increase the PENT requirement or reduce the % of maximum allowable notch for large diameter pipe due to the wall thickness increase.

Equation (3) and (4) are for the same stress. The hoop stress may vary due to several reasons. (1) Different PE pipe grades are used and the HDB can be either 1250 psi or 1600 psi; (2) different design factors may be used to address a given application condition; and (3) the gas utilities may choose to operate their pipeline at a lower pressure. To take into consideration the real stress levels, Equation (2) becomes Equation (5).

$$\left(\frac{S_1 \sqrt{a_1}}{S_2 \sqrt{a_2}}\right)^4 = \frac{PENT_2}{PENT_1} \quad (5)$$

Equation (5) can be used for any two application conditions. They may be two different materials w/o different sizes or for the same material but different pipe sizes. For a given application and to achieve the same satisfactory field performance, the design engineer can balance the pipe operation pressure, pipe diameter and SDR, maximum notch depth, and the minimum PENT requirement.

Taking into consideration both the pipe geometry (diameter and SDR) and residual stress, Dr. N. Brown estimated that 100h PENT would give 100 year lifetime for up to 8” SDR 11 pipe with a 10% notch. A 500h PENT would push up to 24” SDR 11 pipe to a 100 year lifetime with the same 10% notch.

6. Resistance to Rapid Crack Propagation

RCP resistance provides another important material limitation consideration, particularly for 8 inch and larger diameter piping. As operating pressure, pipe diameter and wall thicknesses increase, and operating temperatures decrease, RCP resistance becomes a more and more critical consideration. An RCP “event” is a catastrophic pipe failure in which a crack is initiated and quickly travels along an extended length of pipe. To eliminate the RCP failure, the PE pipeline systems must be operated above the RCP critical temperature or below the RCP critical pressure. Both Full Scale (FS) and Small Scale Steady State (S-4) ISO test methods exist to determine RCP resistance, and the results can provide either the critical pressure or the critical temperature values for the tested material. While this type of event is rare, knowing the material limitations allows for safer design and system operation. Critical pressure is basically the internal pressure above which the material becomes or acts in a brittle fashion and could experience a catastrophic failure. The testing temperature is 0C. The line pressure must be below the RCP critical pressure divided by a RCP design factor of 1.5:1 at 0C and above, see Equation (6).

$$MOP_{RCP} = \frac{P_{c,RCP}}{1.5} \quad (6)$$

$$P_{c,RCP} = P_{c,FS} = 3.6 \times P_{c,S-4} + 2.6 \quad (7)$$

Where $P_{c,RCP}$ can be determined by either Full Scale or S-4 test.

RCP critical temperature is measured at a given internal pressure. 10 bar internal pressure is commonly used for S-4 test in order to cover all pipe sizes. Above RCP critical temperature, RCP will not occur. Below RCP critical temperature, RCP failure can happen if there is an initiation event.

RCP critical temperature is less dependent on pipe sizes. A 10 bar internal pressure is used for the S-4 test. It corresponds to a 38.4 bar RCP critical pressure and maximum allowable operation pressure of 26 bars (371 psig) after taking a design factor of 1.5 to 1. It is 3.8 times the MOP of PE gas pipe (6.9 bars (100 psig)). If the S-4 test is conducted on 10” SDR 11 pipe, it will cover all possible gas pipe sizes with high confidence level that the RCP failure will not happen above the critical temperature. In order to operate the pipeline in the RCP-free region for all PE gas pipe size, a gas utility may require the S-4 critical temperature measured on the pipe samples of 10” SDR 11 is below the minimum application temperature in their operation territory.

If the RCP critical temperature is not available, the critical pressure can be used. It has been found, however, that RCP critical pressure decreases as pipe diameter and wall thickness increases. This is a design concern of using large diameter pipe to replace cast iron and steel pipe. Another concern is that the PE pipe will have a lower critical pressure as SDR increases. This is less an issue since high SDR pipe has a lower MOP. The MOP reduction based on HDB is greater than the MOP reduction based on RCP critical pressure.

The Irwin-Corten equation has been used as a guide for the pipe critical pressure, P_c , for many years.

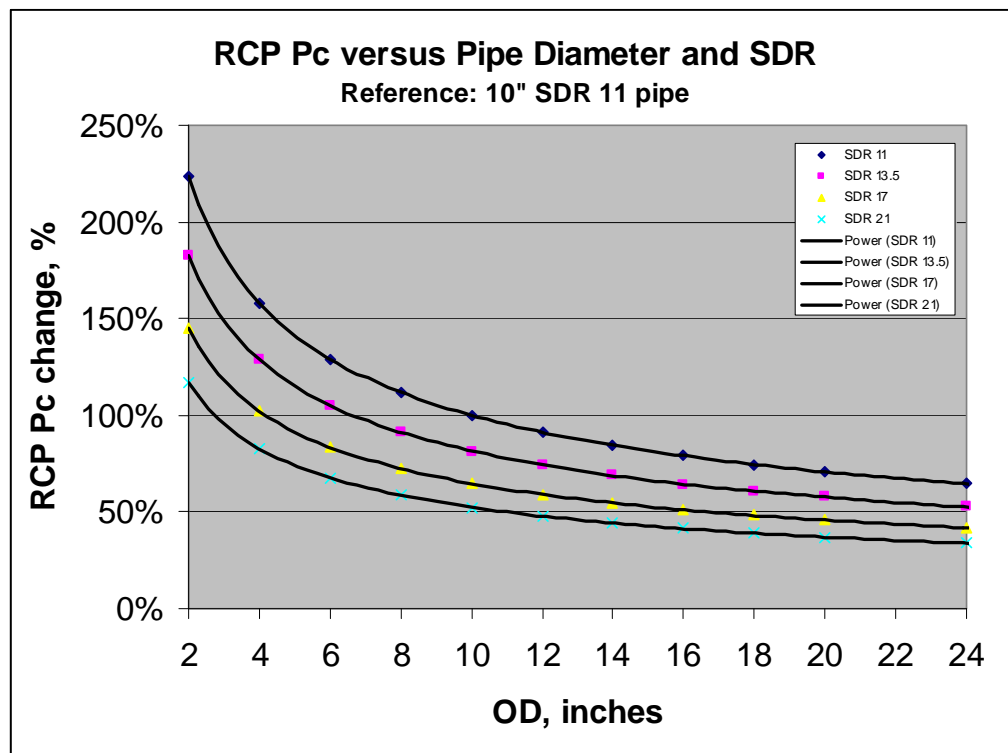
$$P_c = \frac{1}{SDR} \times \left(\frac{8}{\pi \times OD} \right)^{1/2} \times K_D \quad (8)$$

Where OD is the outside diameter of the pipe. For a given PE material, K_D is a constant. From Equation (8), the RCP critical pressure is determined by both pipe diameter and SDR. This is substantially different from Equation (1) where MOP of a PE gas pipe as determined based on HDB is independent of pipe diameter.

The pressure rating of PE gas pipe based on HDB is the same, regardless of pipe diameter, as long as the SDR is the same. However, the MOP based on RCP P_c will be decreased as increasing pipe diameter, as determined by Equation (6).

The RCP critical pressure changes as the pipe diameter and SDR are changed. If we take 10" SDR 11 pipe as the reference, we can calculate the P_c shift from this reference for a given material using Equation (8). Figure 1 illustrates the P_c changes as a ratio to the P_c of 10" SDR 11 pipe. When the pipe diameter increases from 10" to 20", the RCP P_c of 20" SDR 11 pipe is decreased by 29% comparing with 10" SDR 11 pipe made from the same material. To be operated at 100 psig line pressure, the S-4 P_c of 10" SDR 11 pipe must be greater than 2.2 bar (32 psig). However, in order to be operated at 100 psig, the S-4 P_c for 20" SDR 11 pipe must also be greater than 2.2 bar (32 psig). If the S-4 test is conducted on 10" SDR 11 pipe, the RCP P_c requirement should include the P_c shift that is associated with the pipe diameter. The S-4 P_c of 3.1 bars (45 psig) for 10" SDR 11 is equivalent to 2.2 bars (32 psig) for 20" SDR 11 pipe.

Figure 1. Dependence of RCP Critical Pressure on Pipe Diameter and SDR



If the pipe diameter does not change, 10" SDR 13.5 pipe would have a P_c 19% lower than that of 10" SDR 11 pipe. However, changing SDR from 11 to 13.5 will bring down the HDB based pressure rating by 20%. The limiting factor is the HDB based pressure rating not the RCP based pressure rating. In fact,

higher SDR pipe is regarded as having better RCP performance for the same pipe diameter. It is because the reduction of HDB based pressure rating is more than that of RCP based pressure rating.

As discussed earlier, if the RCP critical temperature is measured on 10” SDR 11 pipe specimen and at 10 bar internal pressure, the allowable MOP based on RCP property is 26 bars (371 psig). It enables the pipe made from this material to be operated at 125 psig in the RCP-free zone up to 88” SDR 11 pipe according to Equation (8). Table 3 lists the relative RCP Pc changes when changing pipe diameter and SDR based on the Erwin-Corten Equation (8).

Table 3. Predicted RCP Critical Pressure Shift as a Function of Pipe Diameter and SDR from the reference of 10” SDR 11 Pipe

Nominal Diameter, inches	Predicted RCP Pc Shift				
	DR11	DR13.5	DR 17	DR21	DR26
2	213%	173%	138%	111%	90%
4	155%	126%	100%	81%	65%
6	127%	104%	82%	67%	54%
8	112%	91%	72%	58%	47%
10	100%	81%	65%	52%	42%
12	92%	75%	59%	48%	39%
14	88%	71%	57%	46%	37%
16	82%	67%	53%	43%	35%
18	77%	63%	50%	40%	33%
20	73%	60%	47%	38%	31%
24	67%	55%	43%	35%	28%
36	55%	45%	35%	29%	23%
42	51%	41%	33%	27%	21%

If the S-4 RCP Pc, reported by a resin producer, is 2 bars for 10” SDR 11 pipe, the MOP determined by RCP Pc is 93 psig for the same pipe size. If a gas utility wants to use DR 17 pipe, the MOP as determined by RCP Pc is shifted to 60 psig. The MOP as determined by HDB for DR 17 PE4710 pipe is 64 psig. So this gas utility can operate their pipeline made from this PE4710 at 60 psig and below up to 10” DR 17 pipe. However, if this gas utility wants to operate their pipeline for larger diameters, they may choose to lower the operation pressure. The largest pipe diameters they can use are 42” DR 17 at 30 psig operation pressure and still operate at the safe RCP region. They can also specify a material with higher RCP Pc. With a S-4 Pc of 5 bars (73 psig) on 10” SDR 11 pipe, the gas utility can operate their pipeline at 60 psig up to 42” SDR 17 pipe.

It must be pointed out that the above analysis is based on the predicted RCP Pc from Erwin-Corten equation. It is not based on the measured S-4 test data. Nevertheless, the Erwin-Corten equation can give us a guide to addressing the RCP performance for various pipe diameters and SDR. One reasonable way to address the uncertainty of predicted value is to use a larger safety factor to keep the un-known factors within control. In the above example, the gas utility may require the S-4 Pc of 10 bars (145 psig) on 10” SDR 11 pipe in order to cover larger diameter DR 17 pipe.

It is worth pointing out that it is better to use RCP critical temperature as measured by S-4 by specifying the internal pressure of 10 bars and pipe sample of 10” SDR 11 pipe. By doing this, the pressure is no longer a limiting factor. The only parameter a gas utility needs to address is the application

temperature. As long as the application temperature is above the S-4 critical temperature, RCP failure would not happen for all pipe diameters.

7. Real Life Applications

Having now reviewed in detail the critical material properties and the regulatory requirements, let's sum up the intended direction and materials utilized at PSE&G vs. minimum requirements and critical properties.

7.1. Pipe Diameter

ASTM D 2513 is incorporated into 49 CFR Part 192 by reference and includes material dimensions and tolerances. While the main body of ASTM D 2513 reflects *plastic* pipe diameters up to 12 inch iron pipe size (IPS), the mandatory Annex (A-1) is for PE only and includes additional information on *polyethylene* pipe. It is important to understand that the main body of ASTM D 2513 covers more than just PE materials and the Annexes cover material specific information. The bottom line is that at least since 1996, ASTM D 2513 has reflected PE pipe dimensional requirements for up to 24 inch diameter. There is no 12 inch diameter PE pipe limitation. Perception in parts of the utility industry is that installation of larger than 12 inch diameter piping requires a special permit (waiver) and therefore there is apprehension to design for larger sizes. Regulators are aware of these utility perceptions, and the fact that they hear and do not refute these, adds to the already existing apprehension regarding the rapid advance of PE material properties.

7.2. Operating Pressure

PSE&G is targeting large diameter high SDR pipelines at the operation pressures of 60 psig and below. A 0.32 design factor is intended to be used. The design conditions are below the MAOP of 125 psig (and the MAOP of 100 psig for 14" through 24") as regulated in 49 CFR Part 192. Table 4 lists the typical application conditions. The real design factor used is below 0.32.

Table 4 – Operating Pressure and Stress

Pipe Size	Operating Pressure, psig	MOP, psig	HDB	Operating Stress, psi	% HDB
1-1/4 (0.090)	60	64	1600	428	26.8%
8 (SDR 17)	60	64	1600	380	23.8%
24 (SDR 26)	15	41	1600	188	11.7%

One can easily see from the above that the actual stress on the material can vary greatly, and may be a small percentage of the design capability. It also clearly shows that a large diameter, high SDR pipe may be stressed much lower than what may be normally installed and operated in gas distribution systems. In the above example, one could actually and rightly state that the large diameter high SDR installation is the safest. Remember that one of the boundaries the utility engineer is faced with is return on investment, and therefore pipeline capacity and installation cost is a critical concern. It has been shown many times by proactive utilities in papers and presentation that large diameter PE gas distribution installations are more cost effective to install versus steel. Capacity gains are critical in low to medium pressure system designs, and having the availability of materials that enable large diameter high SDR PE installations to be safely and cost effectively installed is a win for the entire gas industry.

7.3. Slow Crack Growth

As we discussed in Section 5, one perception is that large diameter pipe will fail sooner in SCG because of the increased stress intensity that is associated with the geometry factor. We have shown that by increasing the PENT hours, the large diameter high SDR pipe can perform better than the smaller diameter pipe with shorter PENT hours. The PE4710 materials PSE&G has been using have a documented minimum PENT of 10,000h, much higher than the 500 h PENT requirement for PE4710.

From Equation (3), 24" DR 11 pipe would fail in SCG 16 times faster than 6" DR 11 pipe at the same operating stress and 10% scratch. If a 6" DR 11 pipe made from PE3608 with 100h PENT has satisfactory field performance against SCG, a 24" DR 11 pipe made from PE4710 with 10,000h PENT would perform $10,000/100/16 = 6.25$ times better.

However, in order to replace cast iron and steel gas pipe, large diameter and high SDR pipe is needed. The operation pressure of large diameter high SDR pipe is actually lower. Assuming a 6" DR 11 pipe (0.602" minimum wall) is operated at 100 psig. A 24" DR 21 pipe (1.143" minimum wall) made from the same PE material can be operated at 50 psig. The operating stresses for these two pipes are the same 500 psi. From Equation (3) and at the same notch percentage, 24" DR 21 would have SCG failure 3.6 times as fast as 6" DR 11 pipe. This is because DR 21 has a much smaller relative wall thickness than DR 11. To keep the same 10% notch, the stress intensity of 24" DR 21 is much smaller than that of 24" DR 11 pipe. If 100h PENT can give 6" DR 11 PE3608 pipe a satisfactory field performance against SCG at the operation pressure of 100 psig, 500h PENT is more than enough to give 24" DR 21 PE4710 pipe a satisfactory performance at the operation pressure of 50 psig.

Furthermore, PSE&G, in fact, is looking to operate 24" DR 21 PE4710 at operation pressures of 15 psig and lower. The 24" SDR 21 pipe with 10% notch at 15 psig operation pressures actually will fail in SCG 34 times slower than the 6" SDR 11 pipe with 10% notch at 100 psig operation pressure, for the same pipe materials. Considering the 24" SDR 21 pipe is made from PE4710 with 10,000h PENT and the 6" SDR 11 pipe is made from PE3608 with 100h PENT, the 24" SDR 21 pipe is extremely safe, and will fail about 3400 times slower in SCG.

This prompts PSE&G to use 24" SDR 26 pipe for 15 psig operation pressure. The 24" SDR 26 pipe with 10% notch at 15 psig operation pressures will fail in SCG 22 times slower than the 6" SDR 11 pipe with 10% notch at 100 psig operation pressure, for the same pipe materials. Again, considering the 24" SDR 21 pipe is made from PE4710 with 10,000h PENT and the 6" SDR 11 pipe is made from PE3608 with 100h PENT, the 24" SDR 26 pipe is very safe, and will fail in SCG about 2200 times slower.

7.4. Rapid Crack Propagation

As discussed in Section 6, the RCP critical pressure decreases as pipe diameters increase. The Erwin-Corten equation can be used to calculate the critical pressure shift. Depending on the maximum pipe diameter, this P_c shift can be added to the RCP P_c requirement so as to compensate the pipe diameter factor. If the S-4 P_c on 10" SDR 11 is specified and it meets 10 bars (145 psig) requirement, the high SDR low operation pressure PE gas pipe would be in the RCP-free region up to 24" at the application temperatures above 0C.

If the RCP critical temperature on 10" DR 11 pipe at 10 bar testing internal pressure is required, RCP will not happen for all pipe sizes as long as the application temperature is above this RCP critical temperature.

The Performance Based End Use Specification for Polyethylene Gas Pipe used at PSE&G requires the RCP critical temperature below 20F (-7C). We have given two presentations at previous AGA Operation

Conferences about the establishment and application of this specification. In fact, the PE4710 material used at PSE&G has an S-4 critical temperature of 1F (-17C). It enables the pipe made from this PE4710, regardless of pipe diameters and SDR, to be operated in the RCP-free region.

8. Summary

Utility design engineers have the daunting responsibility to maintain system safety and reliability, operate within compliance, design for long term integrity and reliability, and maximize return on investment. In successfully navigating through this environment the key is to define the environmental boundaries of system operation.

Prudent system design addresses material limitations, and then pressure rating criteria, to ensure both safety and compliance. It has been shown how PE 4710 materials demonstrate a tremendous increase in material performance, and greatly expanded the “safe operating window.”

At PSE&G, we are targeting large diameter PE4710 pipe to replace the current cast iron and steel gas pipe. The pipe diameters range from 12” to 24” with SDR’s ranging from 17 to 26, for use in gas distribution systems operating at 60 psig and lower. The pressure ratings are determined using the 49 CFR Part 192 pressure rating formula and a design factor of 0.32. The direction and targets are within the both the “safe operating window” and the established legal boundaries.

PE 4710 materials provide the opportunity to design for the safe replacement of aging metallic systems. Working within existing code requirements and design formulas, PE *really can* replace large diameter cast iron and steel gas pipe.

References

1. PPI TR-4 - PPI Listing of Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe (2007)
2. ASTM D 2513 - Standard Specification for Thermoplastic Gas Pressure Pipe, Tubing, and Fittings
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