CHANGES TO CSA Z662 “OIL AND GAS PIPELINE SYSTEMS” TO INCORPORATE HIGHER PERFORMANCE PLASTIC PIPE

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ABSTRACT

CSA Z662 is the Standard for the use of plastic pipe in Canadian oil and gas pipeline systems. This paper will give an overview of the recently approved revisions to CSA Z662-11 “Oil and Gas Pipeline Systems”, which will be published next year. These revisions include the following:

- RCP Requirements for PE pipe,
- MRS Design Equation and PE 100,
- HDB Design Factor of 0.45,
- Plus Performance PE materials,
- CRS Methodology,
- Polyamide Materials and
- Reinforced Thermoplastic Pipe.

The paper will discuss the reasons why these revisions to incorporate higher performance plastic pipes were made to the CSA Z662 Standard, and will serve as an introduction to several papers on the use of plastic piping for natural gas distribution in Canada that will be presented at PP XV.

RCP REQUIREMENTS FOR PE PIPE

Although the phenomenon of RCP has been known and researched for several years (1), the number of RCP incidents has been very low. A few have occurred in the gas industry in North America and a few more in Europe. With gas engineers desiring to use PE pipe at higher operating pressures (up to 12 bar or 175 psig) and larger diameters (up to 30” or 750 mm), a key component of a PE piping material - resistance to rapid crack propagation (RCP) - becomes more important.

Most of the original research work conducted on RCP was for metal pipe. As plastic pipe became more prominent, researchers applied similar methodologies used for metal pipe on the newer plastic pipe materials, and particularly polyethylene (PE) pipe (2). Most of this research was done in Europe and through the ISO community.

Rapid crack propagation, as its name implies, is a very fast fracture. Crack speeds up to 200 m/sec (600 ft/sec) have been measured. These fast cracks can also travel very long distances, even hundreds of feet. The DuPont Company had two RCP incidents with its high-density PE pipe, one that traveled about 90m (300 ft) and the other that traveled about 240m (800 ft). RCP cracks usually initiate at internal defects during an impact or impulse event. They generally occur in pressurized systems with enough stored energy to drive the crack faster than the energy is released. Based on several years of RCP research, the probability of an RCP failure in PE pipe is increased with these factors (3):

1. Increase in pipe size/wall thickness
2. Increase in internal pressure
3. Decrease in temperature
4. Decrease in resistance to RCP of the PE material

Typical features of an RCP crack are a sinusoidal crack path along the pipe, and "hackle" marks along the pipe crack surface that indicate the direction of the crack. At times, the crack will bifurcate into two directions as it travels along the pipe.

CSA B137.4 (4) recently added a requirement that RCP testing must be conduced by the resin/pipe manufacturer, but there were no required values. It was decided to leave this up to the Oil and Gas Standard in Z662 Clause 12. The following new clause for RCP was recently added to Clause 12:

> ***12.4.3.6 Rapid Crack Propagation (RCP) Requirements***
> *When tested in accordance with B137.4 requirements for PE pipe and compounds, the standard PE pipe RCP Full-Scale critical pressure shall be at least 1.5 times the maximum operating pressure. If the RCP Small-Scale Steady State method is used, the RCP Full-Scale critical pressure shall be determined using the correlation formula in B137.4.*

A required full-scale RCP critical pressure of 1.5 times the maximum operating pressure is consistent with the RCP requirement in ISO 4437 (5). It is also consistent with the proposed requirement in the AGA Plastic Materials Committee RCP White Paper (6), which requires that the RCP full-scale critical pressure be greater than the leak test pressure. The leak test pressure is 1.5 times the maximum operating pressure.

Recent Small Scale Steady State (S4) testing has shown a dramatic difference in resistance to RCP when comparing traditional unimodal (one reactor) PE materials to bimodal (two reactors) PE materials (3). Table 1 summarizes some typical critical pressure values (S4 and corresponding converted full scale) for various generic PE materials. For most cases, the pipe size tested is 12" SDR 11 pipe.

Table 1. Comparison of Unimodal to Bimodal Critical Pressure for MDPE and HDPE Materials

PE Material	**S4 Critical Pressure ($P_{C,S4}$) at 32°F (0°C)**	**Full Scale Critical Pressure ($P_{C,FS}$) @ 0°C**
Unimodal MDPE	1 bar (15 psig)	6.2 bar (90 psig)
Bimodal MDPE	10 bar (145 psig)	38.6 bar (560 psig)
Unimodal HDPE	2 bar (30 psig)	9.8 bar (140 psig)
Bimodal HDPE (PE 100+)	12 bar (180 psig)	45.8 bar (665 psig)

These data show a ten-fold increase in S4 critical pressure for bimodal MDPE compared to unimodal MDPE, and also a significant increase in S4 critical pressure for bimodal HDPE compared to unimodal HDPE.

MRS DESIGN EQUATION AND PE 100

The Canadian gas companies were aware of the superior properties of the **bimodal** PE 100+ materials (7), as just shown for RCP test results comparing unimodal and bimodal. They were also aware of the ISO MRS (Minimum Required Strength) pressure rating method that utilized a 50-year design basis. As a result, the Canadian gas companies requested that the MRS design equation and the corresponding design coefficient be added to CSA Z662 Clause 12, as shown below.

> ***12.4.2 Thermoplastic piping — Design pressure***
> ***12.4.2.1***
> *Subject to the limitations specified in Clause 12.4.3, piping design pressures shall be determined using either of the applicable formulas as follows:*
> *b) MRS-rated PE materials*
>
> $$P = \frac{2\ MRS \times Fc}{(SDR-1) \times C}$$
>
> *where:*
> *P =design pressure, MPa*
> *MRS = minimum required strength (MPa) - the categorized value of the long-term hydrostatic strength determined in accordance with ISO 9080 and ISO 12162 at a fixed time of 50 years and at a fixed temperature of 20°C. The*

MRS, which is only determined at this fixed time/temperature, is used to classify the PE material, for example, PE 100.

C = design coefficient (MRS or CRS only)

Fc = chemical design factor

12.4.2.2

The design coefficient (C) to be used in the design formula in Clause 12.4.2.1 (b), for MRS (CRS) -rated materials, shall be 2.0

A design coefficient of 2.0 for PE 100 materials in Clause 12 is consistent with the design coefficient of 2.0 for PE materials in ISO 4437, the international standards organization PE gas pipe standard.

To assure that only the superior performing **bimodal** PE 100 materials were allowed for Canadian gas distribution systems when using the MRS methodology, Clause 12 specifies a very stringent slow crack growth (SCG) requirement of 2000 hours PENT. Clause 12 also specifies a very stringent RCP requirement of S4 critical pressure greater than 10 bar, which is consistent with the PE 100+ RCP requirement. Again, only the bimodal PE 100 materials would be able to meet this stringent RCP requirement. These SCG and RCP requirements for PE 100 materials in Clause 12 are shown below.

12.5.2.4 PE 100 compounds

The minimum PENT value for MRS-rated PE 100 compounds using the 2.0 design coefficient shall be 2000 hours, and the minimum RCP Small-Scale Steady State value shall be 1000 kPa at 0°C per Clause 12.4.3.6.

HDB DESIGN FACTOR OF 0.45

The Plastics Pipe Institute (PPI) recently addressed the dilemma that the pressure rating for ISO 9080 PE 100 pipe was higher than corresponding ASTM D 2837 PE 3408 pipe by 45% (8). In an attempt to bring these two pressure ratings methods closer together, PPI increased the design factor from 0.5 to 0.63 for water pipe and from 0.32 to 0.4 for gas pipe. The materials that qualify for the 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 and the new code for PE 2406 became PE 2708 to indicate that these high performance materials qualified for the higher design factor. However, even with this higher design factor, there was still a gap of 15% between the ASTM and ISO pressure rating methods.

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 2708 and PE 4710 were introduced in Canada there was no difference in pressure rating compared to a PE 2406 or PE 3408, respectively. 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.

> ***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 2708 PLUS or PE 4710 PLUS.

PLUS PERFORMANCE PE MATERIALS

The Canadian gas companies wanted to assure that only the superior performing bimodal PE materials would qualify for the higher, 0.45 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. Thus both the HDB rated PE 2708 PLUS and 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°C 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.*

The Tables 2 and 3 below compare the maximum operating pressure for MDPE (medium density PE) and HDPE (high density PE) materials used in SDR 11 pipe:

Table 2: Maximum Operating Pressure (MOP) for MDPE SDR 11 Pipe – Gas Applications

	PE 2406	**PE 2708**	**PE 2708 PLUS**
HDB, psi	**1250**	**1250**	**1250**
Design factor	**0.40**	**0.40**	**0.45**
MOP for SDR 11, psig	**100**	**100**	**112**

Table 3: 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	**0.40**	**0.40**	**0.45**	
Design coefficient				**2.0**
MOP for SDR 11, psig	**125**	**125**	**145**	**145**

From Table 3, you can see that:
- the pressure rating for PE 3408 and PE 4710 are the same,
- 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.

CRS METHODOLOGY

The CRS (Categorized Required Strength) concept was developed within the ISO pressure rating system to provide more flexibility to the design engineer. One of the major uses of CRS is to provide a design basis of 100 years for plastic piping applications. With the CRS concept plastic pipe can now have a design basis or design life of 100 years and be considered equivalent to other piping materials, such as steel or iron pipe, which claim a 100-year design life. Another major application for the CRS concept is to pressure rate plastic pipe at the actual use temperature. This can be useful for high temperature applications or in areas that have a low ground temperature. The design engineer can determine the appropriate conditions for the plastic pipe application, and design accordingly. A PP XIII paper reviewed the CRS concept, how it is validated within ISO 9080, how it is determined within ISO 12162, what its limitations are, and finally, how it is used in typical plastic piping applications to make plastic pipe more cost competitive with metal pipe (9). ISO 12162 recently completed the balloting process to incorporate CRS methodology in ISO 12162, and CSA Z662 Clause 12 has also recently incorporated CRS.

12.4.2.1

CRS = categorized required strength (MPa) – the categorized value of the long-term hydrostatic strength determined in accordance with ISO 9080 and ISO 12162 at a selected design time and at a selected design temperature. The *design engineer may select the appropriate design time and/or appropriate design temperature for the application. The design pressure using CRS is calculated using the same equation as used for the MRS in 12.4.2.1.B.*

Typical times and/or temperatures for CRS include:
Time of 11 years – similar to HDB determined by ASTM D 2837
Time of 100 years – desired design life of 100 years
Temperature of 14°C – higher pressure rating at colder temperature
Temperature of 60°C – maximum temperature for PE

Manitoba Hydro's gas distribution system is designed, constructed and operated under the requirements of CSA Z662 "Oil and Gas Pipeline Systems". Material testing including butt, electro and saddle fusion and pipe squeezing was performed to gain hands on experience with a PE 100 material while a technical investigation of the material was performed. Based on the economic advantages provided and supported by the testing and investigation of the material, application was made to, and approval was received from Manitoba Hydro's regulatory authority to install PE 100 pipe using the MRS pressure rating method. In the summer of 2006, Manitoba Hydro installed 29 kilometers of 114 mm SDR 11 PE 100 pipe by plowing, horizontal directional drill, and open cut methods. This SDR 11 PE 100 pipe has been successfully operating at 145 psig (MRS) with plans to increase to 160 psig based on the CRS (Categorized Required Strength) at 15°C (10).

POLYAMIDE MATERIALS

Polyamide (PA) materials have been used for natural gas distribution in Australia for 40 years, and in the United States for 10 years. With the completion of the ISO 22621 series of standards for PA materials for pressures of 15 to 20 bar (200 to 300 psig), the use of PA for gas applications should increase. CSA Z662 also recently added PA-11 to Clause 12, since it already has an approved product standard – CSA B137.12.

12.4.6.2 Polyamide 11 (PA-11) piping systems
Polyamide-11 pipe, tubing and fittings may be installed in distribution systems in accordance with all the requirements for polyethylene pipe, tubing, and fittings in Clause 12, except that for Polyamide-11 piping systems the maximum operating pressure at elevated temperatures up to 80 ^{O}C shall be based on the published hydrostatic design basis (HDB) value.

Kiwa Gas Technology will be presenting a paper at PP XV comparing the properties of PA 11, PA 12 and PA 612 (11). All three of the PA piping materials show promise as all plastic piping systems that are an alternative to metal pipe for gas distribution pressures up to 20 bar (300 psig). These PA materials also have greater resistance to liquid hydrocarbons as shown in the Clause 12 chemical design factor table below.

12.4.2.3
The chemical design factor (Fc) to be used in the design formula in Clause 12.4.2.1, when liquid hydrocarbons are present, shall be as given in Table 12.1.

Table 12.1
Chemical design factor for thermoplastic pipe and tubing
(See Clause 12.4.2.3.)

Material	***Chemical design factor, Fc***
Polyamide	*1.0*
Polyethylene	*0.5*

REINFORCED THERMOPLASTIC PIPE

Composite pipe technology is an interesting and upcoming field, which will allow plastic pipe to be used at higher pressures, such as 1500 psig (100 bar). One such product is reinforced thermoplastic pipe or RTP. A Canadian RTP manufacturer and a Canadian gas company will be presenting a paper at PP XV on use of RTP for gas distribution applications (12). This is now possible since RTP was recently added to CSA Z662 Clause 12 for gas distribution applications. RTP is also included in Clause 13 for gas gathering applications.

12.4.6.3 Continuous length reinforced thermoplastic pipe and fittings
Continuous length reinforced thermoplastic pipe (RTP) Type 1 may be installed in distribution systems in accordance with the requirements for RTP pipelines in Clause 13.1, except that the Maximum Pressure Rating (MPR) in the design equation in Clause 13.1.2.8 shall be established on the basis of a minimum life expectancy of 50 years. The requirements of Clause 13.1.1.3 do not apply.

CONCLUSIONS

In this paper we have discussed several revisions that have been made to the Standard for Canadian gas applications described in CSA Z662 Clause12. These include:

- Added RCP required value of a full-scale critical pressure greater than 1.5 times the maximum operating pressure for PE materials.
- Added the MRS design equation so that PE 100 pipe could be installed and pressure rated using the ISO pressure rating method. Specified stringent SCG requirement of 2000 hours PENT and S4 RCP critical pressure of 10 bar for bimodal PE 100 materials.
- Added a higher design factor of 0.45 so that the pressure rating for HDB-rated and MRS-rated pipes would be the same. Introduced “PLUS” marking to indicate that the 0.45 design factor could be used.

- Specified stringent SCG requirement of 2000 hours PENT and S4 RCP critical pressure of 10 bar for HDB-rated PLUS materials, to be consistent with the requirement for bimodal PE 100 materials. This would include the bimodal PE 2708 PLUS and bimodal PE 4710 PLUS materials.
- Incorporated the CRS methodology to provide the gas engineer with more flexibility in design his gas system. This includes pressure rating at the desired use temperature for the desired time.
- Added PA-11 as a piping material for higher-pressure gas piping applications up to 300 psig (20 bar). Also, added a chemical design factor table, which points out that PA materials are not affected by liquid hydrocarbons.
- Added reinforced thermoplastic pipe (RTP) for even higher-pressure gas piping applications up to 1500 psig (100 bar).

These revisions the CSA Z662 Clause 12 will help to promote the use of plastic pipe in the Canadian gas distribution system. Use of plastic pipe results in a more cost-effective and safer piping system compared to steel pipe, which has a history of higher leak rates and corrosion. The future for plastic pipe is very bright in Canada!

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