Clarification Regarding High-Density Polyethylene Pipe (HDPE)

This document presents an analysis of the different standards covering high density polyethylene (HDPE) pipe used in the geothermal industry. This document is distributed for informational purposes only to geothermal industry stakeholders and other interested parties.

CSA Standards – Context

There are a certain number of standards which frame the geothermal industry. Standard CAN/CSA C448 Series-02 Design and Installation of Earth Energy Systems (C448) undoubtedly contains the largest number of recommendations and guidelines. In terms of the use of pipe for geothermal systems, standard C448 refers to standard CAN/CSA B137.1 Polyethylene Pipes, Joints and Fittings for Cold Water Piping (B137.1).

In September 2009, following numerous questions raised by the Canadian GeoExchange Coalition (CGC) and multiple industry stakeholders, the Canadian Standards Association (CSA) published a “Technical Information Letter” concerning modifications to standard B137.1. Changes to the norm stipulated that pipes must be identified as follows:

Marking

The pipe shall be permanently or indelibly marked at intervals not exceeding 1.5 m with at least the following:

(a) the nominal size;
(b) the manufacturer’s name or trademark;
(c) the date or date code of manufacture;
(d) the material designation (“PE3408”);
(e) the intended service (“Geothermal” or “C448”);
(f) the series number;
(g) “Inside Diameter Pipe” or “Outside Diameter Pipe” or “Tubing”, as appropriate; and
(h) The CSA Standard Designation (“CSA B137.1”).

The pipe shall not carry the word “potable” or the letters “P” or “PW” on its surface.

The marking on the pipe shall be in accordance with Clause 7.1.2 of CSA B137.0.

Our research indicates that these specifications concerning marking are a minimum requirement. We conclude that providing supplementary information is not prohibited.

Designation Numbers for HDPE Pipe

PE3408 vs PE3608

Standard B137.1 specifies cell composition numbers 345564 or 345434, in reference to ASTM D3350-01 (2001 edition). That said, since the revision of standard ASTM D3350 in 2005 (ASTM D3350-05), the cell classification limits were changed. Before 2005, the category of PE4710 would have been listed in the same class as PE3408 since the class had no subdivisions. ASTM D3350-01 was also changed, with the addition of a higher class of slow crack growth resistance (SCG), Density, tensile strength and Hydrostatic Design Strength (HDS) to differentiate PE4710 from PE3408.

At present, classification under ASTM D3350-05 requires cell classifications including 345564 or 345434, and a classification of 445574 for PE4710. The designation PE3408 or PE3608 determines if one must compare cell classification with the old standard ASTM D3350-01 (pre-2005) or to the new standard ASTM D3350-05. Before 2005, PE3408 could have a different slow crack growth resistance speed (calculated in hours) for the same PE3408, as two different cell classifications carried the same pipe designation. Today, PE3608 refers only to one category of HDPE resins. This implies that PE3608 possesses all the mechanical properties of PE3408 but that PE3408 does not necessarily possess all the mechanical properties of PE3608. To lessen confusion, pipe manufacturers dealing with standard ASTM D3350-05, who wish to produce correctly marked pipe per C448 usually mark their pipe “PE3408/PE3608.” Therefore the current version of C448 refers to a product where the mechanical properties are inferior to other products available on the market and which are listed under standard ASTM D3350-05.

These standards are unfortunately not updated in a synchronised manner, and this creates serious problems of interpretation when one standard refers to another. Frequently some standards do not reflect current science – either basic or advanced science – or new industry best practises. Many innovations may fall under of imply other standards which are more up to date and reflective of market realities. Common sense and logic should therefore prevail when interpreting a set of standards.

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Given that standard C448 has not been updated in some time, C448 as a document does not reflect the proper cell classification defined in ASTM D3350-05. As a consequence of this disconnect in updating / currency, PE4710 (cell classification 445574) is not part of the 1999 version of standard B137.1, which standard C448 requires. PE3408, for its part, figures largely in C448 but is no longer mentioned in the 2009 version of B137.1.

Further, according to the older ASTM D3350-01 which C448 refers to, PE3408 is the only pipe number mentioned, given that C448 even in its updated version (dated October 2009), still does not reflect the changes made within standard ASTM D3350 in 2005 and in the 2010 update.

**PE4710 vs PE3608**

Following the 2005 revision of standard ASTM D3350, PE4710 was given a cell classification including a 445574 resin. Comparing cell classification of PE3608 (345564) and PE4710 (445574), it's evident that the mechanical properties of PE4710 equal or surpass those of PE3608. For more information, the detailed cell classification limit table from standard ASTM D3350-05 is provided below.

**PE100**

PE100 is governed under International Standards Organisation (ISO) standards, and first appeared on the European market in 2002. In fact the introduction of this product in North American markets inspired the changes reflected in standard ASTM D3350 in 2005. Improvements in the category of Slow Crack Growth Resistance (SCGGR) allowed resin manufacturers to push the boundaries of these resins in other areas. One such area includes hydrostatic strength classification as well as design life. PE100 pipes have higher Pressure capabilities as well as a minimum service life of 100 years compared to that of a 50 year service life for other HDPE resins.

The designation number awarded to PE100, as a function of its mechanical properties according to ASTM D3350-05, is PE4710. Currently, according to a list maintained by National Safety Foundation (NSF), cell classification of PE100 is 445576. A unique cell classification distinction between PE4710 and PE100 is the last cell. This means that PE4710 and PE100 respond similarly, with some improvements, to the same fundamental properties – cell classification limits – for density, for fusion index, flexural modulus, for tensile strength at yield, and elongation at break.

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<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Limit Classifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, g/cm³</td>
<td>D1505</td>
<td>&gt;0.925 or &gt;0.925, &gt;0.940, &gt;0.947, &gt;0.955, Specify Value</td>
</tr>
<tr>
<td>Melt index</td>
<td>D1238</td>
<td>&gt;1.0 to &gt;0.4 to &gt;0.15</td>
</tr>
<tr>
<td>Flexural modulus, MPA (ps)</td>
<td>D790</td>
<td>&lt;138 (20 000 to &gt;60 000)</td>
</tr>
<tr>
<td>Tensile strength at yield, MPA (ps)</td>
<td>D636</td>
<td>&lt;15 (2250)</td>
</tr>
<tr>
<td>Slow Crack Growth Resistance</td>
<td>D1899</td>
<td>A, B, C, C, C, Specify Value</td>
</tr>
<tr>
<td>Hydrostatic Strength Classification</td>
<td>D2937</td>
<td>5.52, 6.98, 8.62, 11.00, Specify Value</td>
</tr>
<tr>
<td>Hydrostatic design, MPA (ps), (29°C)</td>
<td>ISO 12162</td>
<td>1000, 1000, 1000, 1000, 1000, 1000, 1000</td>
</tr>
<tr>
<td>Minimum required strength, MPA (ps), (30°C)</td>
<td>ISO 12162</td>
<td>1162, 1162</td>
</tr>
</tbody>
</table>

Compliance with physical properties in accordance with Section 8 is required including requirements for cell classification, color, and ultraviolet (UV) stabilizer, thermal stability, brittleness temperature, density, tensile strength at yield, and elongation at break.

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establish different pressure capacities for a given pipe, made from that resin.

**Standard B137.0**

*Section 6.6.3.1*: Pressure ratings of pipe of various dimensions shall be calculated from the hydrostatic design basis (HDB) or the minimum required strength (MRS) value for the specific compound used to make the pipe. The introduction of a second method (minimum required strength, MRS) for determining the hydrostatic design strength in a pipe has led to the possibility of calculating different pressure ratings for a pipe made with a given PE compound. The designer shall determine the appropriate usage of either the MRS or HDB rating system, in combination with the appropriate service design factors (for HDB) or service design coefficient (for MRS), when calculating a pressure rating for a given application.

**Colour and UV Protection**

Over the course of its useful life, polyethylene pipe and joints of the same composition will be exposed to daylight, usually during their temporary site storage and their transport. As a consequence, ultraviolet rays (UV), combined with oxygen, may have repercussions on the physical properties of polyethylene, including the deterioration of the pipe material itself. To avoid negative effects, UV stabilizers are usually added to the natural resins during pipe manufacture.

Two distinct parameters must be considered when dealing with UV protection issues. The first is pipe resistance to weather, i.e. a pipe resin’s ability to retain its physical properties when exposed to the elements, and the second, often used to evaluate the durability of a pigment is called “colour solidity,” which is a tested measure of time until a pipe bleaches or changes colour.³

In terms of classification, according to ASTM D3350-05 and reiterated in ASTM D3350-10, five (5) possible designations exist to determine colour and UV-ray protection:

<table>
<thead>
<tr>
<th>Code Letter</th>
<th>Color and UV Stabilizer</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Natural</td>
</tr>
<tr>
<td>B</td>
<td>Colored</td>
</tr>
<tr>
<td>C</td>
<td>Black with 2% minimum carbon black</td>
</tr>
<tr>
<td>D</td>
<td>Natural with UV stabilizer</td>
</tr>
<tr>
<td>E</td>
<td>Colored with UV stabilizer</td>
</tr>
</tbody>
</table>

One of the above designation letters appears at the end of every 6-character pipe marking string, to clearly identify the resin used in pipe fabrication. Generally, this designation letter denotes the pigmentation and the UV stabilizers found in the finished polyethylene of a particular pipe. For example, PE4710 refers to classification PE445574A, i.e. the resin in its natural state, but this may eventually be identified as PE445574C or even PE445574E for geothermal purposes. The multiple resin classification tests (for example a resin density test) are executed on the natural resin, before pigmentation, as prescribed by standard ASTM D3350-10.

**Deficiencies in Certain Standards**

In the course of its market transformation initiative and its efforts to unify the geothermal heat pump industry, CGC staff and CGC Accredited Professionals have identified many anomalies and weaknesses in codes, standards and regulations that principally affect the industry in Canada. Piping issues form part of this generalized and at times industry-crippling problem. For example, some contradictions concerning requirements for underground pipe are found in section 5.2 of standard C448.1-02, which addresses Underground Piping Materials and Series Requirements. The text of articles 5.2.1.1 and 5.2.3 stipulate the following essentially contradictory elements:

*Article 5.2.1.1*: Underground and underwater polyethylene pipe and fittings for ground-heat exchanger systems shall [...] d) meet the cell classification 345564 or 345434 as specified in ASTM Standard D 3350.

*Article 5.2.3*: Plastic components to be joined by fusion shall be manufactured to the same specifications and be of the same resin compound type, with cell classifications 345564C or 345434C.

Considering that the phrases “polyethylene pipe and fittings” and “plastic components to be joined by fusion” refer to the same idea, a contradiction inherently exists in C448.1-02 regarding the required resin type classification. Article 5.2.1.1 makes no mention of any designation letter for colour or UV protection, while article 5.2.3 takes the same cell classification for fused plastic elements (and therefore for the polyethylene joints cited in 5.2.1.1). This time however the standard adds the letter C, that is, the criteria “black with a minimum of 2% carbon black.” If one were required to interpret standard C448 to the letter, as many municipal inspectors are, nothing forbids us from fusing pipe where UV protection properties are not defined or known, to pipe where UV protection properties are defined – a generally nonsensical outcome.

To add more complexity to this situation, C448.1-02 article 5.2.1.1 requires that underground and/or submerged pipes and fittings conform to CSA standard B137.1. This latter standard is specific to polyethylene pipes, tubes, and fittings which serve for cold water under pressure, i.e. mainly potable water. In fact there are a series of standards under the series B137. Within the B137 series, standard B137.0 covers the general requirements for piping under thermal pressure: certain articles therefore apply to polyethylene pipes used in geothermal piping as well. The requirements here for colour and UV protection are:

**Standard B137.0**

*Section 4.1.4 Stabilizers, lubricants, and pigments*: The compound may contain stabilizers, lubricants, and pigments proven not to be detrimental to the pipe, tube, tubing, fittings, or plastic accessories.

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**Section 4.2.4 Ultraviolet (UV) radiation protection:**
Plastics used in the manufacture of pipe and fittings that are sensitive to ultraviolet (UV) exposure or have no natural resistance to UV exposure shall be compounded to provide UV stabilization. The level of stabilization shall be dependent on end-use requirements and the sensitivity of the plastic to UV exposure.

**Standard B137.1**

**Section 4.2.4 Ultraviolet (UV) stabilization:** PE compounds shall have a colour code of B, C, or E as specified in ASTM D 3350. Black (weather-resistant) compound with a colour code of C shall comply with Clause 4.2.5 of this standard.

**Section 4.2.5.2: Carbon black shall:**
(a) be a furnace black;
(b) have an arithmetic mean diameter not exceeding 58 nm (as measured by electron microscopy); and
(c) yield a nigrometer reading not exceeding 87.

The carbon black content shall comprise not less than 2% of the compound when determined in accordance with ASTM D 1603.

Section 4.2.4 of standard B137.1 stipulates that the resin designation letter must be C, E or B, while more generally standard B137.0 requires that the plastics which are sensitive to UV rays be protected from this exposure. Consequently, in the absence of logical links between the various articles of C448 that irregularly mention this designation letter, CGC considers that the resin may be coloured or simply black (B137.1) and that the resin must be finished with an anti-UV protection (per B137.0).

The colour and UV protection classification of polyethylene pipes and fittings used in geothermal pipe must therefore be classified as B, C, or E, as prescribed by standard B137.1.

**Conclusions**

CGC staff have reached the following conclusions based on the above interpretation. It bears repeating that these are technical, not legal opinions, based on a close reading of confusing and contradictory standards.

**Acceptable pipe designations**

PE3608, PE4710 and PE100 surpass or meet the requirements of [the old version of] B137.1, which refers to PE3408. The cell classification of these is superior or equal in reference to standard ASTM D 3350-05. To maintain minimal requirements for pipe marking, it is acceptable that manufacturers print the pipe designation (PE3408, PE3608, PE100 or PE4710) as well as the designation PE3408 if using PE3608, PE100 or PE4710.

**Minimum SDR requirements**

Minimum number requirements for “standard dimension rating” (SDR) remain the same as those specified in standard C448, with little effect from the resin designation numbers. It is true that a PE4710 resin resists higher pressures than PE3608 for a given SDR, except that standard B137.1 has not yet defined matters regarding equivalences in SDR using different resins. Until the next revision is published, CGC reminds installers and designers to review and respect table one of standard C448.1-02 regardless of the resin’s designation number.

<table>
<thead>
<tr>
<th>Outside nominal size, mm (in)</th>
<th>Vertical pipe series number</th>
<th>Horizontal pipe series number</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 (3/4)</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>25 (1)</td>
<td>125</td>
<td>125</td>
</tr>
<tr>
<td>32 (1-1/4)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>38 (1-1/2)</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>50 (2)</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>75 (3)</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>100 (4)</td>
<td>42</td>
<td>42</td>
</tr>
</tbody>
</table>