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TECHNICAL ASSESSMENT OF ROTH X-PERT 5S® TUBING FOR USE IN HYDRONIC HEATING APPLICATIONS

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Executive Summary

This white paper provides a technical assessment of the suitability of Roth's 5-layer X-PERT brand PE-RT pipe for use in the US hydronic heating market. The assessment was based on technical reports, product certifications and standards, and the specific requirements of hydronic heating applications, as well as an on-site visit and assessment of the US manufacturing facility. The basis of the product's technology, the EVOH oxygen barrier, the 5-layer construction and the PE-RT structural component of the tubing, is examined along with the capabilities of the US manufacturing facility to produce consistent, quality piping. The product standards and performance characteristics of Roth's X-PERT S5® tubing are also examined and compared to those of conventional PEX materials. The paper concludes with an examination of the market information and usage history for PE-RT and 5-layer tubing.

The X-PERT S5® 5-layer technology is seen to provide significant benefits in protecting the EVOH barrier layer during installation and operation and brings significant advantages to hydronic applications. The Dowlex™ 2344 structural component of X-PERT S5® tubing has had a long successful history in hydronic heating applications and meets the long-term, slow crack growth and oxidative resistance demands of hydronic heating applications. Further, the standard requirements and expected performance are very similar to those of the incumbent PEX materials. Overall, the assessment concludes that the Roth X-PERT S5® product has the performance capabilities required for the US hydronic heating market and is manufactured in a state-of-the-art production facility that is fully equipped to produce consistent, quality tubing.

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1.0 Overview

Roth has recently introduced a flexible 5-layer PE-RT (Polyethylene of Raised Temperature) tubing product, X-PERT S5® (hereafter referred to as X-PERT S5®), to the North American hydronic heating and cooling market. The product contains an EVOH oxygen barrier layer in the middle of the tubing wall, bonded to PE-RT structural layers of Dowlex™ 2344 resin, and has been introduced to complement Roth's existing 5-layer PEX tubing product, DUOPEX S5®.

Given the critical role that tubing plays in the successful long-term performance of hydronic heating systems, a technical assessment of the suitability of this product for the application was conducted. The assessment was based on a review of technical reports, certifications and listings, industry standards and the specific requirements of hydronic heating applications. A site visit and assessment of the US manufacturing facility was also conducted.

Tubing for hydronic applications must provide protection for oxygen ingress through the tubing, long-term pressure strength under the operating conditions of hydronic systems, meet the applicable performance standards and meet the installation demands of the application. The assessment, therefore, considered the basis of the X-PERT S5® technology in meeting the performance demands of hydronic systems, the standard requirements for hydronic applications and conformance of the X-PERT S5® tubing to these standards and the system design and installation of the tubing. The history of PE-RT and 5-layer tubing in hydronic applications was also examined to provide further insight into the suitability of the technology for the application.

2.0 Basis of X-PERT 5S® Technology

There are four critical components of the X-PERT S5® technology: (1) the EVOH oxygen barrier layer, (2) the 5-layer construction used to protect the oxygen barrier, (3) the manufacturing process and (4) the PE-RT resin that forms the structural component of the pipe wall. A technical assessment of each of these was conducted, focusing on the general performance capabilities and the ability to produce quality product. Based on this analysis, it is seen that Roth's X-PERT S5® technology is well suited for hydronic heating applications and produced using a state-of-the-art manufacturing process that will ensure the quality of the product for hydronic applications.

2.1 Oxygen Barrier

Oxygen barriers are used in flexible plastic tubing for hydronic heating applications to protect the hydronic heating system components from corrosion. The Roth technology uses a layer of EVOH (an ethylene vinyl alcohol copolymer) bonded to the structural layers of the pipe to provide this barrier to oxygen diffusion. This is a widely accepted method for retarding the ingress of oxygen

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through the pipe into the hydronic system. Further, the ASTM specifications for both PEX[1] and PE-RT[2] tubing allow for the inclusion of such a barrier layer in otherwise homogenous tubing.

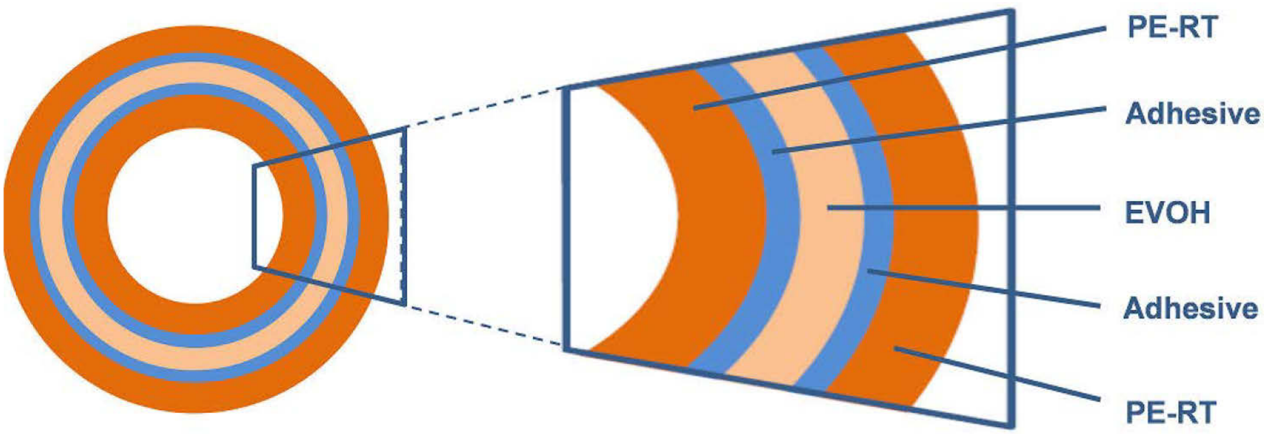
While the general technology is well established, no US standard is in place for assessing the effectiveness of the oxygen barrier layer. DIN Standard 4726[3] does, however, include such a requirement based on testing to ISO 17455[4]. After conditioning of the pipe under specific conditions, the water is partially de-oxygenated below its equilibrium solubility at the test conditions to provide a driving force for oxygen permeation through the tubing wall. The oxygen content of the water is then monitored and the flux, or flow per unit area, of oxygen is determined. Based on the DIN 4726[3] standard, the tubing must demonstrate ≤ 0.32 mg/(m^2•d) at 104˚F (40°C) and ≤ 3.60 mg/(m^2•d) at (176˚F) 80°C.

The Roth X-PERT S5® tubing meets these DIN requirements for oxygen barrier performance[5], providing a measured level of oxygen permeability resistance that assures performance.

2.2 Five-Layer Technology

Two basic technologies are used to include a barrier layer into plastic tubing products for hydronic heating applications, referred to as 3-layer and 5-layer constructions. In a 3-layer construction, the barrier layer is extruded on the outer pipe surface and bonded to the pipe using an adhesive layer. The three layers, from inside to outside, are (1) inner structural polymer layer, (2) adhesive layer and (3) EVOH layer. The outer layers (EVOH and adhesive) are typically co-extruded at the same time as the bulk pipe, although some processes involve pipe production and then separate application of the barrier layer and adhesive. For the Roth 5-layer barrier technology, the barrier layer is actually co-extruded in a middle layer of the pipe so that it is fully protected during installation and in service. The layers, from inside to outside as shown in Figure 1, are (1) inner structural polymer layer, (2) adhesive layer, (3) EVOH Layer, (4) adhesive layer and (5) outer structural polymer layer. Although there are five layers, there are only three materials and only two types of bonding required: adhesive to structural polymer and adhesive to EVOH. The 5-layer construction is the simplest configuration that fully protects the EVOH layer while bonding all layers tightly.

Figure 1: X-PERT 5S® 5-Layer Barrier Piping



A technical comparison was made of the 3 and 5-layer constructions examining three critical aspects: (1) the ability of the EVOH layer to retard oxygen ingress through the tubing wall, (2) the overall integrity of the EVOH barrier layer during installation and operation and (3) the impact of the barrier layer and construction on tubing performance and manufacturability. Table 1 provides a summary comparison of these factors. The performance is seen to be similar, with two notable exceptions: the 5-layer construction provides significant advantages in protecting the integrity of the barrier layer during installation and operation, and manufacturing of 5-layer piping is, technically, a more complex process. Based on the technical complexity of the 5-layer process, an assessment of the US manufacturing process for Roth's X-PERT S5® tubing was conducted and is reported in Section 2.4.

As discussed previously, EVOH layers in hydronic barrier tubing have been shown to be capable of providing protection from oxygen migration through the pipe wall and both constructions are, therefore, able to provide an effective oxygen barrier. As shown by the measured performance of X-PERT S5® tubing to the DIN standard[6], incorporation of the EVOH in the mid-wall of the pipe construction delivers this performance.

Table 1: Comparison of 3 and 5-Layer Barrier Piping

Property		3-Layer Tubing	5-Layer Tubing
1. Ability to Provide Effective Oxygen Barrier		**Yes**	**Yes**
2. Integrity of Barrier Layer	Bonding to base polymer	**Yes**	**Yes**
	Protection of oxygen barrier during shipping and handling	No	**Yes**
	Protection of oxygen barrier during installation	No	**Yes**
	Protection of oxygen barrier in service from wear due to thermal expansion and contraction	No	**Yes**
	Protection of EVOH layer from moisture	No	**Yes**
3. Ability to produce pipe with no impact on tubing performance		**Yes**	**Yes**
4. Ease of manufacture		Easier	More Difficult

In terms of the bonding of the EVOH layers, the same types of adhesives are used in both 3 and 5-layer constructions. They form the same type of bonds, between the EVOH and the structural polymer layer, in both constructions. When properly selected for the right bond strength and temperature performance, over twenty years of successful field performance has demonstrated that a strong, functional bond can be made to ensure bonding between the EVOH and structural polymer layer for both constructions.

The primary advantage of the 5-layer construction over 3-layer construction is the protection of the EVOH layer from damage during shipping & handling, installation and operation. The EVOH layer is relatively thin and damage to the outer pipe surface in 3-layer construction can cause penetration of this layer, reducing the effectiveness in prohibiting oxygen penetration through the pipe wall. This type of damage can occur in pipe handling through dragging of the pipe over rough surfaces, from gouges, from cuts etc. During operation, the expansion and contraction of the tubing with heating and cooling can lead to abrasion or wear of the outer EVOH layer, again reducing overall effectiveness. The EVOH layer's effectiveness is also decreased on moisture exposure (the barrier properties decrease with increasing moisture adsorption in the EVOH layer). The X-PERT S5® 5-layer construction provides protection from all of these mechanisms.

Long-term tubing performance depends on the ability to incorporate the barrier layer into the tubing and achieve strength equivalent to a solid wall tube of the same structural polymer without a

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barrier layer. This is relatively easy to achieve with a 3-layer construction, as the EVOH layer is essentially extruded on top of the existing base solid wall pipe with no impact on the structural integrity of the base tubing. For 5-layer constructions, as the EVOH layer is in the middle of the structural pipe wall, a more detailed analysis is required to ensure performance. Accordingly, an analysis of the impact of the barrier layer in 5-layer constructions on the short- and long-term strength and long-term oxidative resistance according to ASTM F2023[6] was conducted. In terms of short-term strength, 5-layer tubing must meet the same performance requirements as monolayer tubing for both PE-RT and PEX materials. This provides a minimum level of assurance that the tubing performance will be equivalent. For long-term hydrostatic strength, testing has shown that 5-layer tubing has the same hydrostatic strength as monolithic tubing of the same structural polymer. Jana Laboratories conducted extensive research into the impact of 5-layer constructions on the long-term oxidative stability of tubing testing in accordance with ASTM F2023[6]. This research[7] ultimately led to the testing approach used to qualify that barrier tubing has equivalent oxidative resistance to the base tubing with no barrier layer. The ASTM F2023[6] test methodology is a stringent test that involves testing tubing at elevated temperatures (up to 239˚F) under harsh environmental conditions and has been found to quickly identify any tubing defects or weaknesses, including poor bonding of the pipe layers. In this testing, properly constructed 5-layer tubing with good bonding between the layers is seen to have equivalent performance to solid wall tubing of the same structural polymer, providing further evidence that the barrier layer does not impact long-term performance of 5-layer tubing. Equivalency testing of X-PERT S5® to confirm equivalent performance to solid wall Dowlex™ 2344 tubing was conducted as part of the listing process[8], providing further validation that the internal barrier layer does not negatively impact pipe performance.

The 5-layer extrusion process, with the EVOH layer in the middle of two PE-RT layers, is more complex than that for the standard 3-layer technology with the EVOH simply extruded as the outer layer. This requires greater control during the extrusion process. An analysis of the US manufacturing process was conducted and is summarized in the section following.

With quality manufacturing, however, the X-PERT S5® technology is seen to provide significant benefits in protecting the EVOH barrier layer during installation and operation and brings significant advantages to hydronic applications.

2.3 Manufacturing Process

The Roth US manufacturing process was examined to assess its ability to produce pipe with a consistent EVOH layer accurately positioned within the pipe wall with well controlled dimensions, all of which are critical to performance of the pipe and oxygen barrier. It was found that the Roth X-PERT S5® tubing is manufactured in a state-of-the-art US manufacturing facility with state-of-the-art processing controls to ensure product consistency.

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The tubing is produced in continuously extruded lengths with all five layers being brought together during the extrusion process using a specially designed co-extrusion die. Continuous 360° ultrasonic layer measurement tied to a sophisticated control system is used to ensure that the EVOH barrier layer is properly positioned in the pipe wall and that all pipe dimensions, for every foot of pipe, are in specification. The system is fully integrated with feedback control of the gravimetric feeders, extruders and puller speed based on the dimensional measurements from the 360˚ ultrasonic dimensioning unit, which continuously monitors the dimensions of the inner PE-RT, EVOH and outer PE-RT layers. Off-line QC testing is also conducted per the ASTM F2623[2] standard. This level of production control is very much state-of-the-art for hydronic tubing manufacturing in the US and Europe.

Housekeeping at the production facility was impeccable.

The manufacturing process and production facility are NSF-14 certified for the production of PE-RT barrier tubing in accordance with ASTM F2623[2]. This process entails a quality audit of the production facility along with third party performance testing of the finished product, providing further assurance of the quality of the manufacturing process.

Overall, therefore, the manufacturing process and facility were found to be very much state-of-the-art and fully capable of producing high quality X-PERT S5® tubing on a consistent basis.

2.4 Structural Polymer - PE-RT Resin

It is the structural polymer that provides the long-term strength properties of 5-layer tubing. This material must, therefore, be able to meet the performance demands of hydronic heating applications. The performance capabilities of the PE-RT structural layer in Roth's X-PERT S5® tubing relative to the demands of hydronic heating applications were examined. Based on this examination, it was concluded that the PE-RT resin has the required performance properties for hydronic heating applications.

Dow's Dowlex™ 2344 PE-RT is the structural polymer in Roth's X-PERT 5S® tubing. It is an advanced polyethylene material based on a combination of Dow technologies – constrained geometry catalyst technology, polymerization solution technology and ethylene octane co-monomer process technology. The resulting molecular architecture is touted to provide the high-temperature performance advantages of PEX while retaining the advantages of non-cross-linked polyethylene (PE)[9]. In order to assess the technical capabilities of this material for hydronic heating applications, four key areas were examined: (1) the historical use of the material in hydronic heating applications, (2) the long-term pressure strength relative to the requirements of hydronic applications, (3) the slow crack growth (SCG) resistance and (4) the oxidative resistance.

2.4.1 Dowlex™ 2344 Historical Usage in Hydronic Applications

Dowlex™ 2344 is a proven, thoroughly tested material with a service history of 29 years in hydronic heating applications and more than one million miles of installed pipe around the world[10]. Fifteen developed countries accept or approve Dowlex™ 2344 for heating applications, including the US and Canada. The US is also one of seven developed countries where Dowlex™ 2344 is approved for potable water distribution.

Dowlex™ 2344 was introduced to North America almost a decade ago, originally as the PE-RT component of PE-RT/Aluminum/PE-RT composite tubing per ASTM F1282. It has been listed by the Plastics Pipe Institute (PPI) and NSF International since 2003. In 2007, ASTM F2623[2] *Standard Specification for Polyethylene of Raised Temperature (PE-RT) SDR 9 Tubing* was published, covering PE-RT only tubing, with or without an EVOH layer, followed by ASTM F2769 *Standard Specification for Polyethylene of Raised Temperature (PE-RT) Plastic Hot and Cold-Water Tubing and Distribution Systems* for potable water applications in 2010.

The Dowlex™ 2344 resin that forms the structural layers of the ROTH X-PERT S5® tubing is, therefore, a proven material in hydronic heating applications with three decades of history.

2.4.2 Long-Term Pressure Strength

The critical factor in determining if a material has the long-term pressure strength required for the application is to characterize that strength based on the standard ASTM methods (ASTM D2837[11], PPI TR-3[12]) and compare that long-term strength to the requirements of the application.

For hydronic applications, tubing in a modern high-efficiency floor heating installation typically does not see an internal fluid temperature greater than 110°F. This is particularly true for floor heating that is supplied by a Ground Source Heat Pump (GSHP), as those systems typically cannot generate temperatures much above that value. There is, however, one-third of new installations today that operate above 140°F at least some of the time. A smaller fraction is operated at or near a fluid temperature of 180°F. These higher temperatures are needed for low-conductivity floor installations, such as retrofit systems installed below wood floor/subfloor construction. The high thermal resistance of such flooring requires a greater thermal gradient to drive enough heat into the living space than a more conductive installation. Thus, tubing for the floor hydronic heating market needs to perform reliably at any temperature up to 180°F.

Dowlex™ 2344 is listed in PPI TR-4[13] with Hydrostatic Design Basis (HDB) ratings at 73˚F and 180˚F. Based on these ratings, SDR 9 tubing manufactured from Dowlex™ 2344 has pressure ratings of 200 psig at 73°F and 100 psig at 180°F and, thus, is capable of providing the long-term pressure strength required for hydronic applications, which typically operate in the 12-15 psig range and rarely exceed 20 psig operating pressure.

2.4.3 Slow Crack Growth Resistance

Slow Crack Growth (SCG) is another critical performance property in hydronic applications due to the potential high temperatures. The SCG properties of the Dowlex™ 2344 resin were examined and found to meet the requirements for hydronic applications.

SCG is a failure mechanism that can occur in polyethylene (PE) pipe materials and result in a significant decrease in the long-term pressure strength. This mechanism is accelerated by temperature, making high temperature applications such as hydronic heating impractical for standard PE materials. It is for this reason that PE materials are cross-linked to produce PEX (cross-linked PE) materials. With sufficient levels of cross-linking, the SCG mechanism is, for all practical purposes, eliminated.

Dowlex™ 2344 achieves high SCG resistance through the unique molecular architecture of the material without the need for cross-linking. This enables it to perform in higher temperature applications. The material has been validated through elevated temperature testing to ensure that a transition to SCG behavior does not occur at the 180°F listing temperature per the policies of PPI TR-3[12]. This validation at the highest temperature rating of 180˚F provides a high level of assurance that SCG will not occur in service in hydronic applications.

The PENT test (F1473 *Standard Test Method for Notch Tensile Test to Measure the Resistance to Slow Crack Growth of Polyethylene Pipes and Resins*[47]) provides another measure of SCG resistance. The Dowlex™ 2344 resin used in Roth's X-PERT S5® tubing has a PENT value greater than (ASTM F1473 at 80°C and 2.4 MPa stress) 7,000 hours. By comparison, the minimum value required for high performance PE 4710 material is 500 hours. This high PENT value provides further confirmation of the high SCG resistance achieved by the tailored molecular architecture of the Dowlex™ 2344 resin and the resulting suitability for use in hydronic applications up to 180˚F.

2.4.4 Oxidative Resistance

In elevated temperature applications like hydronic heating, the long term oxidative stability of the structural polymer is also a critical performance factor and was, therefore, examined for the Dowlex™ 2344 resin used in the Roth X-PERT S5® tubing.

The primary method for assessing the long-term oxidative resistance for PEX and PE-RT materials was developed for assessing performance of piping materials for hot and cold potable water applications, where, due to the disinfectants added to the potable water to protect it from biological growth, a relatively aggressive oxidative environment is created[14]. These systems are considered to be significantly more oxidatively aggressive than closed loop hydronic heating systems, as the disinfectants (oxidants) are continually replenished in potable water systems, which is not the case for closed loop hydronic heating systems. With the added protection of the oxygen barrier ,preventing oxygen diffusion into the piping system, hydronic heating system fluids are, therefore, much less oxidative than those found in potable water applications. Even though this method is for demonstrating performance in more oxidatively aggressive environments, testing to ensure oxidative resistance for PE-RT materials based on this approach has been included in ASTM F2623[2]. Specifically, ASTM F2623[2] requires testing to ASTM F2023[6] to demonstrate a minimum 50 years oxidative resistance under specific end-use conditions. Both Dowlex™ 2344[15] and Roth's X-PERT S5®[16] tubing have been qualified based on these requirements to provide assurance that the materials have a high level of oxidative resistance and are, therefore, considered capable of long-term performance in hydronic heating applications.

Overall, therefore, the Dowlex™ structural component of X-PERT S5® tubing is seen to have a long successful history in hydronic applications and meets the long-term, SCG and oxidative resistance demands of hydronic heating applications.

3.0 Standard Requirements

ASTM F2623[2] *Standard Specification for Polyethylene of Raised Temperature (PE-RT) SDR 9 Tubing* is the applicable US standard for Roth's X-PERT S5® tubing. This section summarizes the performance requirements of this standard, the ability of the X-PERT 5S® tubing to meet these requirements and makes a comparison with the standard requirements for PEX materials (ASTM F876[1] *Standard Specification for Cross-linked Polyethylene (PEX) Tubing*).

The base material for X-PERT S5®, Dowlex™ 2344, is also certified by NSF International. Dowlex™ 2344 is certified as meeting the requirements of ASTM D3350[17], with a cell classification of 223273A. The material complies with NSF/ANSI 61 health effects requirements when tested at temperatures up to and including 180°F and the chlorine resistance requirements of ASTM F2023.

Roth's X-PERT S5® tubing is certified by NSF International to ASTM F2623[15] in 3/8", 1/2", 5/8", 3/4" and 1" diameters. The certification is for hydronic heating applications only. In addition to meeting the requirements of ASTM F2623, X-PERT S5® meets the Quality Assurance requirements on NSF/ANSI Standard 14 and the NSF Plumbing Systems Components Certification Program Policies. This product must undergo annual performance testing to confirm continued compliance with the performance requirements of ASTM F2623. In addition, the manufacturing facility

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receives annual unannounced audits to verify continued compliance with the Quality Assurance requirements of ASTM F2623 and the NSF Certification Program Policies. While X-PERT S5® is not certified for use in potable water distribution systems, as mentioned earlier, the tubing does meet the chlorine resistance requirements of ASTM F2623 when tested in accordance with ASTM F2023[6]. Roth's X-PERT S5® is also certified by NSF International to the Uniform Mechanical Code™ and should be installed in accordance with the manufacturer's instructions and the requirements of the latest edition of the Uniform Mechanical Code™.

Table 2: Standard Requirements for PE-RT and PEX Tubing in the US

Requirement	**PE-RT (ASTM F2623-08)[2]**		**PEX (ASTM F876-10)[1]**
Workmanship	Same requirements		Same requirements
Barrier Layers	Allowed		Allowed
- Barrier Dimensions	Must meet dimensional requirements of standard with barrier layer included		Must meet dimensional requirements of standard with barrier layer included
- Performance Requirements	Equivalent HDS Rating to non-barrier PE-RT		Adhesion Test per ASTM F1281
Dimensions	SDR 9 Sizing		SDR 9 Sizing
Pressure Ratings	Minimum (psig)	X-PERT S5® (psig)	Minimum (psig)
73°F	160	200	160
140°F	100	-	not applicable
180°F	80	100	100
200°F	not applicable	-	80
Sustained Pressure Test	Pressure (psig)		Pressure (psig)
73°F	330		330
180°F	165		195
200°F	not applicable		165
Burst Pressure	Pressure (psig)		Pressure (psig)
73°F	480		480
180°F	180		215
200°F	not applicable		185
Slow Crack Growth (SCG)	Minimum (hrs)	X-PERT S5®	
PENT	500	>7000	not required
Environmental Stress Cracking	not required		100 hr test with surfactant
Oxidative Stability			
Stabilizer Functionality	not required		3000 hrs @ 120°C 8000 hrs @ 110°C
Oxidative Stability	Chlorine Resistance minimum 50yrs per 9.1.1 of ASTM F2023		Not required for hydronic tubing
Bent Tube			
Cold Bend	Radius 6x's OD, Sustained pressure @ 180°F		Radius 6x's OD Sustained pressure @ 180°F
Hot Bend	not required		Radius 2.5x's OD Sustained pressure @ 180°F

The standard requirements for PE-RT and PEX are very similar. Both have the same requirements for workmanship and the same sizing (SDR 9). In addition, both allow the use of barrier layers and the performance tests, with some difference in requirements and specific methods, cover the same areas of pressure strength, SCG, oxidative stability and bent tube testing. A comparison of the two standards is provided in Table 2, above.

The minimum pressure ratings are 160 psig at 73°F for both PEX and PE-RT, with PE-RT having a lower 180°F minimum pressure rating (80 psig versus 100 psig for PEX) due to the softer, more flexible nature of the PE-RT material (recall X-PERT S5® ratings exceed these minimum requirements and are 200 psig and 100 psig for 73°F and 180°F, respectively). For the same reason, the 180°F sustained and burst pressure requirements are roughly 20% lower for the PE-RT tubing. The sustained and burst tests are for qualification against minimum expected material performance only. It is the pressure rating of the material upon which long term performance should be considered. On this basis, the X-PERT S5® meets or exceeds the minimum pressure ratings of PEX at 73°F and 180°F.

Different testing approaches are applied in the two standards for SCG and Oxidative Stability. For SCG, the PE-RT standard has a minimum PENT requirement; for PEX, there is a minimum requirement based on testing pipe with surfactant (an accelerator of SCG). The PE-RT material, through the PPI TR-3[12] listing process, further requires validation of the linearity of the 180°F regression line to ensure that there is not a transition to the SCG failure mechanism. In terms of oxidative stability, the PEX standard requires Stabilizer Functionality testing of pipe at elevated temperatures, while the PE-RT standard requires chlorine resistance testing in accordance with ASTM F2023[6]. The latter is considered to be a considerably more aggressive test. The PE-RT standard is, therefore, considered to be at least as aggressive as the PEX standard for these properties.

The requirements for cold bend tubing testing are the same for the two standards. Hot bend tubing testing is not a requirement of the PE-RT standard, as hot bending is not a recommended practice for PE-RT tubing.

Overall, the standard requirements are very comparable and materials meeting the requirements of either standard would be expected to perform as intended in hydronic heating applications.

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4.0 System Design and Installation

The design and installation of the X-PERT S5® tubing system in hydronic applications is virtually identical to that of PEX tubing. The tubing has the same flow and thermal properties of PEX, is highly flexible, is available in long lengths and uses the same fitting systems.

The 5-layer continuous extrusion process used in Roth's US manufacture of X-PERT S5® tubing enables production of tubing in the long coiled lengths required for hydronic heating applications. The continuous dimensional monitoring ensures the integrity of each foot of pipe in the coil. Table 3 provides a comparison of the reported densities and flexural modulus values for PE-RT and PEX materials obtained from product brochures. The Dowlex™ 2344 material, with the lowest density (0.933 g/cm³) and flexural modulus (550 MPa), provides for a very flexible pipe material relative to typical PEX materials. Combined, therefore, X-PERT S5® tubing is able to provide the flexible, long coil lengths required for installation in hydronic systems.

Table 3: Comparison of Reported Density and Flexural Modulus Values for PERT and PEX

Property	Material			
	PERT Dowlex™ 2344	PEX-a[1]	PEX-b[2]	PEX-c[3]
Density (g/cm^3)	0.933	0.938	0.947 – 0.952	0.936 – 0.948
Flexural Modulus (MPa)	550	n/r	0.760 – 0.841	680 - 760

Notes: 1. Peroxide PEX, 2. Silane PEX, 3. E-beam PEX, all values taken from product brochures and specification sheets obtained from an on-line search.

X-PERT S5® tubing has the same dimensions (SDR 9) as PEX tubing and can be joined by standard crimp insert fittings that are manufactured in accordance with ASTM F-877, F-1807 and F2159.

PE-RT and PEX materials have essentially the same coefficient of thermal expansion and, therefore, the two materials will demonstrate nearly identical linear expansion and contraction in the application. The same design approaches used for PEX materials to accommodate this can, therefore, be used with the Roth X-PERT S5® tubing.

5.0 PE-RT and 5-Layer Pipe History in Hydronic Applications

Both PE-RT and 5-layer piping construction have a long history in hydronic applications. This history is further confirmation of the suitability of the X-PERT S5® technology for hydronic heating applications.

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Overall, 44.8% of the hydronic tubing market in Europe is 5-layer tubing; both PEX and PE-RT utilizing five-layer technology have been on the market for over 20 years. While relatively new to North America, PE-RT has come to be a dominate material in the European heating market, as shown in Table 4[18]. PE-RT had an estimated 26.9% of the European floor heating market in 2010, second only to PEX. As discussed previously, PE-RT has a 29 year history in hydronic tubing applications. Roth's market share of both PEX and PE-RT in the European Heating and Plumbing applications is 13%.

Table 4: PE-RT Materials a Dominate Material in Western European Heating and Plumbing Market[18]

Year	Percent Market Share					
	PEX	PE-RT	PP-R	PB	Multilayer	Metal
2007	47.4%	24.0%	1.6%	4.5%	19.2%	3.3%
2008	47.6%	24.8%	1.5%	4.2%	19.0%	2.8%
2009	46.5%	26.4%	1.4%	4.0%	18.8%	2.8%
2010	46.6%	26.9%	1.3%	4.2%	18.3%	2.7%
2011	47.2%	27.1%	1.3%	4.1%	17.7%	2.6%
2012	47.3%	27.2%	1.3%	4.0%	17.6%	2.5%
2013	47.3%	27.3%	1.3%	4.0%	17.7%	2.5%

6.0 Case Studies

Dow installed an innovative hydronic hydronic heating and cooling system, based on plastic pipes made with Dowlex™ 2344 PE-RT resin in its European headquarters two decades ago. The installation was one of the first non-residential installations of a PE-RT hydronic heating and cooling system. The installation involved 131,000 feet of 16 x 2mm diameter plastic pipe in the concrete foundation, walls and ceilings of a four-story building.

As part of a refurbishment project, Dow had an opportunity to examine and analyze a section of the pipe system to see how it performed after 20 years of service. Dowlex™ 2344 material from the pipe was subjected to differential scanning calorimetry (DSC) analysis, a thermo-analytical technique to measure whether any change had occurred in its melting and crystallization behavior relative to a reference sample. DSC results are indicative of brittleness or degradation; the Dowlex™ 2344 material was still faring well. The second test conducted was an oxidative induction time (OIT) measurement at 210° C. This test is a means of characterizing the thermo-oxidative stability of polyolefins and is used to determine if the original stabilization components are still present and capable of protecting the material against oxidation. The results of the OIT test on the Dowlex™ 2344 material showed that more than 60% of the original OIT is still available to offer long-term oxidation protection for the pipe.[19]

7.0 Summary

A Technical Assessment of Roth's X-PERT S5® tubing technology was conducted to determine the product's suitability for hydronic heating applications.

The four critical components of the X-PERT S5® technology – (1) the EVOH oxygen barrier layer, (2) the 5-layer construction used to protect the oxygen barrier, (3) the manufacturing process and (4) the PE-RT resin that forms the structural component of the pipe wall – were assessed independently, focusing on the general performance capabilities and the ability to produce quality product. Based on this analysis, it is seen that Roth's X-PERT S5® technology is well suited for hydronic heating applications and produced using a state-of-the-art manufacturing process that will ensure the quality of the product for hydronic applications.

By protecting the EVOH barrier layer, the five layer technology is seen to provide significant advantages for handling, installation and operation of hydronic systems and the EVOH layer itself has been demonstrated through testing to provide the barrier protection required to protect the rest of the hydronic system from oxygen damage. The structural layers of the tubing are comprised of Dowlex 2344 resin, a material with a thirty year proven track record in hydronic systems and the required performance capabilities for the application. X-PERT S5® tubing meets the requirements of ASTM F2623[2] *Standard Specification for Polyethylene of Raised Temperature (PE-RT) SDR 9 Tubing* and is NSF International certified for hydronic applications. With performance and standard requirements very similar to PEX piping materials, X-PERT S5® tubing is expected to perform equally well in hydronic applications.

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About Jana Laboratories Inc.

Jana is the largest piping systems knowledge solutions firm in the world. Jana's primary engineering office, headquartered just outside of Toronto, Canada is supported by Jana's ISO 17025 accredited laboratory. Jana wields the most sophisticated engineering capability in the world, the largest oxidation resistance test and analysis capacity in the world, and the largest hydrostatic test capacity in North America. With over 45 years piping systems testing & engineering experience and a budget of over $2,500,000 in R&D over the past five years, Jana's knowledge sets the bar for the industry. Jana's services have supported the installation of over one billion meters of pipe globally. More information about Jana can be found at www.janalab.com.

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Dr. Ken Oliphant is Executive Vice President of Jana. Dr. Oliphant received his undergraduate degree in Chemical Engineering from the University of Toronto and his Doctorate degree in Chemical Engineering from Queens University at Kingston, Ontario. He has spent his entire career in the Plastic Piping Systems industry with specific focus in plastic piping system performance validation and lifetime forecasting.

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