Plastic Piping Materials for Ground Source Geothermal Systems

A presentation by the Plastics Pipe Institute

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The Plastics Pipe Institute

PPI Represents All Sectors of the Plastic Pipe Industry
- PPI was formed in 1950 to develop test methods for plastic pressure pipes
- Today: Non-profit trade association serving North America

PPI Mission: To advance the acceptance and use of plastic pipe systems through research, education, technical expertise and advocacy

Members: PPI members share a common interest in broadening awareness and creating opportunities that expand market share and extend the use of plastics pipe in all of its many applications

2020: Over 170 members firms involved with the plastic pipe industry around the world

Website: www.plasticpipe.org
The Plastics Pipe Institute

PPI Represents All Sectors of the Plastic Pipe Industry
- PPI’s five divisions focus on solutions for multiple applications:
  - **Building & Construction Division (BCD)**
  - Drainage
  - Energy Piping Systems
  - Municipal & Industrial
  - Power & Communications

**BCD Materials:** PEX, CPVC, PE-RT, PEX-AL-PEX, PP, HDPE (Geothermal)
The Plastics Pipe Institute

PPI’s Building & Construction Division (BCD)
BCD is focused on plastic pressure pipe and tubing systems used within buildings and on building premises for applications such as plumbing, water service, fire protection, hydronic heating and cooling, snow and ice melting, district heating and cooling, and ground source geothermal piping systems.

BCD involvement with industry groups:
Ground Source Geothermal Systems

Ground Source Geothermal
- Ground source heat pumps are the most efficient source of heating and cooling energy for any type of building (vs. VRF, boilers, chillers, etc.)

System Benefits:
- Piping loops exchange heat with the Earth
- Geothermal heat pumps can have efficiencies (COP) greater than 450% when operating in heating mode
- Heat is rejected to the earth when cooling (high EER)
- Heat pumps are indoors, out of sight, no noise
- Low operating costs, high reliability, economical

Example of horizontal ground loops
Ground Source Geothermal Systems

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Example of vertical ground loops

Courtesy IGSHPA

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Ground Source Geothermal Systems

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Example of submerged pond loop

Courtesy IGSHPA
Ground Source Geothermal Systems

Relevance
The last two PPI BCD Project of the Year winners have been Geothermal projects:
- **2018: Whisper Valley** Net-Zero Capable Community in Austin, TX (**REHAU**)
  - 237 homes with PEXa double U-bends in a community geo system (313,000 ft of pipe)
Ground Source Geothermal Systems

Relevance
The last two PPI BCD Project of the Year winners have been Geothermal projects:
- **2019: YVR Airport** Geoexchange System in Vancouver, BC (Versaprofiles)
  - 841 boreholes 500 ft deep with PE4710 loops plus headers (841,000+ ft of pipe)
Presentation Outline

This presentation will:

1. Describe the **plastic piping materials** used for ground source geothermal systems
   - HDPE  *high density polyethylene*
   - PEX  *crosslinked polyethylene*
   - PE-RT  *polyethylene of raised temperature resistance*
   - PP  *polypropylene (PP-R and PP-RCT)*

2. Discuss the industry **standards** that apply to these piping materials

3. Demonstrate various **manifold** and **header** techniques

4. Introduce **PPI TN-55** and other industry resources of piping information
Plastic Piping Materials

Drinking Water Safety
- All plastic tubing, pipes and fittings intended for potable (drinking) water shall meet the requirements of NSF/ANSI/CAN Standard 61 Toxicological Evaluation for Materials in Contact with Drinking Water (“Health Effects”)

1.1 Purpose “This Standard establishes minimum health effects requirements for the chemical contaminants and impurities that are indirectly imparted to drinking water from products, components, and materials used in drinking water systems.”
Plastic Piping Materials

“Tubing vs. Pipe”
- “Tubing”: the actual Outside Diameter is 1/8 inch larger than the nominal size
- “Pipe”: the actual Outside Diameter matches that of iron/steel pipe of the same nominal size, or products where the actual OD matches the nominal size

- Tubing uses nominal sizes such as ‘NTS 3/4’; also known as Copper Tube Size (CTS)
- Pipe uses nominal sizes such as ‘NPS 3/4’; also known as Iron Pipe Size (IPS)
Plastic Piping Materials

Dimension Ratios
- **Most** plastic pipe and tubing uses a *Standard Dimension Ratio (SDR)*
- Standard Dimension Ratio - the ratio of outside diameter to wall thickness, calculated by dividing the average outside diameter of the tubing by the minimum wall thickness
- Examples:
  - PEX tubing is **SDR 9** (wall thickness is 1/9 of the OD)
  - CPVC tubing is **SDR 11** (wall thickness is 1/11 of the OD)
  - HDPE pipe may be **SDR 9, SDR 11, SDR 13.5**, etc.

- Within a *Standard Dimension Ratio*, each diameter of the pipe type (e.g. ¾, 1, 2) has the same pressure capability & rating

*Exception: Pipes that follow **Schedule 40/80** dimension schemes*
Plastic Piping Materials

Pipe Design Factor / Safety Factor
- All plastic tubing, pipes and fittings have inherent safety factors for the intended applications based on prescribed Design Factors within product standards

- Mandatory Design Factors reduce the listed operating pressures by up to 50%*
  *Certain PE 4710 materials utilize a 0.63 design factor

- Pressure - Temperature ratings are based on an extrapolated time-to-failure prediction using a 0.50 Design Factor on pressure; actual capability is 2x the listed pressure

- Plastic systems demonstrate Long-term Hydrostatic Strength (LTHS) through established test methods such as ASTM D2837 and listings according to PPI TR-3 Policies and Procedures for Developing Hydrostatic Design Basis (HDB) and Hydrostatic Design Stresses (HDS) for Thermoplastic Piping Materials
1. Plastic Piping Materials for Geo Systems

The piping material is critical to the success of the ground loop system

- Piping must provide corrosion resistance, chemical resistance, flexibility, impact resistance, resistance to slow crack growth, long-term hydrostatic strength (pressure capability), and temperature resistance

- Piping systems may experience changes in pressure up to 60 psig (415 kPa) due to thermal expansion/contraction of heat transfer fluid and the pipe itself

- Piping systems may experience changes in temperature from 25°F to 115°F (-4°C to 46°C)

- Geothermal piping materials must also provide suitable heat transfer capabilities
Plastic Piping Materials for Geo Systems

**HDPE: High Density Polyethylene**
- High density polyethylene (HDPE) is the most common type of piping material used for ground heat exchangers, with decades of proven service for this application
- HDPE is recognized in virtually all codes and standards as an approved material for ground-coupled heat exchange piping systems (aka “ground loops”)
- Strong and tough material, suitable for applications up to 140°F (60°C)

**Common types:**
- PE 3608, PE 4710 (material designation codes)

*Coil of HDPE piping with molded U-bend already fused to pipe ends*
Plastic Piping Materials for Geo Systems

HDPE: On the job
Plastic Piping Materials for Geo Systems

HDPE: On the job

Courtesy Versaprofiles

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Plastic Piping Materials for Geo Systems

HDPE: Thermal Properties
- See PPI Handbook of Polyethylene Pipe 2nd Edition, Table E.1
- Specific Heat: 0.46 BTU / lb - °F
- Thermal Conductivity: 3.1 BTU-in/ft²-hr-°F (PE 4710)

<table>
<thead>
<tr>
<th>Thermal Property</th>
<th>PE2XXX</th>
<th>PE3XXX</th>
<th>PE4XXX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of Thermal Expansion/Contraction(°F)</td>
<td>1.0 x 10⁻³</td>
<td>9.0 x 10⁻³</td>
<td>8.0 x 10⁻³</td>
</tr>
<tr>
<td>Specific Heat BTU / LB - °F</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Thermal Conductivity (BTU - in/ hr - sq. ft- °F)</td>
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<td>3.0</td>
<td>3.1</td>
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</table>
Plastic Piping Materials for Geo Systems

HDPE: Connections
- HDPE connections are typically via heat fusion
  1. Butt fusion (pipe-to-pipe or fitting-to-fitting) joints according to ASTM Standard D3261
  2. Socket fusion (pipe-to-fitting) joints according to ASTM Standard D2683
  3. Electrofusion (pipe-to-fitting) joints according to ASTM Standard F1055
- Fusion joints shall be installed in accordance with ASTM Practice F2620
Plastic Piping Materials for Geo Systems

HDPE: Connections
- **ASTM F2620** *Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings*
  - is the industry’s practice for heat fusion
  - First published in 2006, latest edition 2019
Plastic Piping Materials for Geo Systems

**HDPE: U-bends**
- HDPE U-bends can be fabricated from elbows, or
- Molded from the same polymer as the pipe material

*U-bend fabricated with butt-fused elbows*
*Molded HDPE U-bend already fused to pipe ends*
*Coil of HDPE pipe with U-bend*
Plastic Piping Materials for Geo Systems

**HDPE: U-bends**

- HDPE U-bends can be fabricated from elbows, or
- Molded from the same polymer as the pipe material
- Examples of Molded U-bends in three sizes, factory-fused to HDPE pipes

*Image Courtesy Centennial Plastics*
Plastic Piping Materials for Geo Systems

PEX: Crosslinked Polyethylene
- Crosslinked polyethylene (PEX) is modified HDPE with enhanced capabilities
- PEX is a high-temperature, flexible pressure pipe, over 40 years of use globally
- Widely used for plumbing, water service, fire protection, hydronic heating and cooling, snow and ice melting and ground source geothermal piping systems
- Strong and tough material, suitable for applications up to 180°F (82°C) and beyond

Common types:
- PEX 1206, PEX 3306 (material designation codes)

Illustration of PEX “molecule”
Plastic Piping Materials for Geo Systems

PEX: On the job

Courtesy REHAU
Plastic Piping Materials for Geo Systems

PEX: On the job

Photo: Google

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Plastic Piping Materials for Geo Systems

PEX: Thermal Properties
- See PPI TR-48/2014
- *R-Value and Thermal Conductivity of PEX & PE-RT*

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity $\text{BTU} \cdot \text{in}/(\text{ft}^2 \cdot \text{hr} \cdot \degree\text{F})$</th>
<th>Thermal Conductivity $W/(\text{m} \cdot \degree\text{K})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>PEX</td>
<td>2.86</td>
<td>0.41</td>
</tr>
<tr>
<td>PE-RT</td>
<td>3.15</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Plastic Piping Materials for Geo Systems

PEX: Connections
- Connections are typically via compression fittings or electrofusion

Cold-expansion compression-sleeve PEX fitting as per ASTM F2080

HDPE electrofusion fitting on PEX tubing as per ASTM F1055
Plastic Piping Materials for Geo Systems

PEX: Connections
- Connections are typically via compression fittings or electrofusion

Press-sleeve PEX fitting as per ASTM F3347

Cold-expansion PEX fitting as per ASTM F1960
Plastic Piping Materials for Geo Systems

**PEX: U-bends**
- PEX U-bends may be factory-formed from continuous pipe using heat, or
- Fabricated using special s/s fittings approved for direct burial

*PEX U-bend encased in resin tip (two)  PEX U-bend with compression-sleeve fittings Double U-bend configuration*
Plastic Piping Materials for Geo Systems

PE-RT: Polyethylene of Raised Temperature Resistance
- PE-RT is HDPE material with enhanced capabilities to withstand higher temperatures
- PE-RT has a 35-year history of successful use in the European market
- Strong and tough material suitable for applications up to 180°F (82°C)
- PE-RT piping can be joined via heat fusion or compression fittings

Common types:
- PE 2708, PE 4710 (material designation codes)
Plastic Piping Materials for Geo Systems

**PP: Polypropylene**
- There are **two types** of PP pressure piping materials:
  - *Random copolymerized polypropylene (PP-R)* is a high-temperature plastic pressure piping system first used for plumbing and hydronics, now for geothermal
  - *Polypropylene random copolymer with modified crystallinity & temperature resistance (PP-RCT)* is a stronger grade of PP material, higher tensile strength
Plastic Piping Materials for Geo Systems

**PP: Connections**
- Connections are typically via **heat fusion**
- Various mechanical fittings (e.g. grooved) and adapters are also available

Courtesy Aquatherm
Plastic Piping Materials for Geo Systems

PP: Connections
- **Electrofusion** joints have embedded copper wires that heat the fitting, welding it to pipe ends; a computerized machine controls the process.
Plastic Piping Materials for Geo Systems

Plastic Piping Material Applications
- Each of these materials may be used for geothermal ground loops and energy piles
- HDPE and PEX are sometimes supplied for double-U-bend configurations

*PEX in rebar cage/structural pile*  
*Double U-bends*
Plastic Piping Materials for Geo Systems

Summary
- The four plastic piping materials used for geothermal ground loop systems are:
  - HDPE  *high density polyethylene*
  - PEX  *crosslinked polyethylene*
  - PE-RT  *polyethylene of raised temperature resistance*
  - PP  *polypropylene (PP-R and PP-RCT)*

- Each of these materials provides corrosion resistance, chemical resistance, flexibility, impact resistance, resistance to slow crack growth, long-term hydrostatic strength (pressure capability), and temperature resistance, as well as good thermal conductivity.
2. Industry Standards for Plastic Piping

Importance of proper standards

- Each of these piping materials delivers long-term reliability, proven through decades of use around the world

- The life expectancy of these plastic piping materials, when installed according to industry and manufacturers’ guidelines, is typically well in excess of fifty (50) years

- Long-term pressure ratings are based on ASTM Test Method D2837 with materials listed according to PPI TR-3

- Piping materials are specified through rigorous product standards with detailed testing requirements for materials and performance, as well as strict industry certification programs to ensure consistent quality control
Industry Standards for Plastic Piping

Importance of proper standards

- Project specifications that cite inappropriate pipe standards can cause confusion with manufacturers, the supply chain and installers
- Specifying an out-of-date or inappropriate standard for geothermal pipes may violate requirements of relevant mechanical codes while potentially increasing costs
- Project specifications that combine inappropriate or incompatible requirements, sometimes pulled from various sources with the best intentions, can create the need for products that don’t exist!

- Sometimes referred to as “Frankenstein specs”
Industry Standards for Plastic Piping

NSF 358 Standards

- A series of standards specifically for the geothermal ground loop industry
- Includes special test requirements:
  - Compatibility with antifreeze mixtures
  - Tensile pull-out tests for connections
- Pipe manufacturers can get their products certified to 358-x

- NSF 358-1 HDPE
- NSF 358-2 PP
- NSF 358-3 PEX
- NSF 358-4 PE-RT
Industry Standards for Plastic Piping

**HDPE: High density polyethylene**

Suggested language:

- *All HDPE pipe and fittings shall be manufactured from a PE compound with a minimum pipe material designation code of PE3608 when evaluated in accordance with ASTM D3350, and a minimum hydrostatic design stress (HDS) value of 800 psi at 73°F (23°C)*

- *HDPE pipe shall comply with one or more of the following product standards: ASTM D3035, ASTM F714, or CSA B137.1*

- *All HDPE pipe and fittings shall meet the requirements of NSF 358-1*
Industry Standards for Plastic Piping

PEX: Crosslinked Polyethylene

Suggested language:

- All PEX tubing shall be manufactured with a minimum pipe material designation code of PEX1206 when evaluated in accordance with ASTM F876 and a minimum Hydrostatic Design Stress (HDS) value of 630 psi at 73°F (23°C)

- PEX tubing shall comply with one or more of the following product standards: 
  **ASTM F876, F2788** or **CSA B137.5**

- All PEX tubing and fittings shall meet the requirements of **NSF 358-3**
Industry Standards for Plastic Piping

PE-RT: Polyethylene of Raised Temperature

Suggested language:

- All PE-RT tubing shall be manufactured from a PE compound with a minimum pipe material designation code of PE3608 when evaluated in accordance with ASTM D3350, and a minimum hydrostatic design stress (HDS) value of 630 psi at 73°F (23°C)

- PE-RT tubing shall comply with one or more of the following product standards: 
  \[ \text{ASTM F2623, F2769, or CSA B137.18} \]

- All PE-RT tubing and fittings shall meet the requirements of \text{NSF 358-4}
Industry Standards for Plastic Piping

PP: Polypropylene

Suggested language:

- All PP pipe and fittings shall be manufactured from a PP compound with a minimum required strength (MRS) of 10 MPa (1,450 psi) at 68°F (20°C) when evaluated in accordance with ISO 9080

- PP-R and PP-RCT pipe and fittings shall comply with one or more of the following product standards: ASTM F2389 or CSA B137.11

- All PP pipe and fittings shall meet the requirements of NSF 358-2
Industry Standards for Plastic Piping

IGSHPA Design & Installation Standards

- Updated regularly over the years
- Includes HDPE & PEX
- Planning to be “retired” soon
Industry Standards for Plastic Piping

IAPMO Uniform Mechanical Code

- Latest 2021 edition published in March 2020

- Appendix F is Geothermal Energy Systems

- Contains Installation, Piping Requirements, Testing, and more
Industry Standards for Plastic Piping

Uniform Solar, Hydronics & Geo Code

- Latest 2018 edition published in September 2018
- Chapter 7 is Geothermal Energy Systems
- Contains *Installation*, *Piping Requirements*, *Testing*, and more
Industry Standards for Plastic Piping

ANSI/CSA/IGSHPA C448-16

- C448 is the ANSI designated bi-national consensus standard for the design and installation of ground source heat pump systems

- First published in February 2016

- This Standard was developed by a Bi-national Technical Committee comprised of the industry's leaders from Canada and USA

- Contains **Piping Requirements** and much more
Industry Standards for Plastic Piping

Summary

- It is important to properly select and specify the correct type of ground loop piping materials using current industry products and correct specific language, to avoid misunderstandings with suppliers and installers

- Each of the plastic piping materials used for ground loops can be specifically specified

- Use of and reference to IAPMO UMC or USHGC or ANSI/CSA/IGSHPA C448-16 will help to ensure proper design and installation of geothermal systems
3. Manifold and Header Techniques

Manifolds and Headers
- Most ground source geothermal projects require more than one loop of heat exchange piping for the required heat transfer capacity
- Header systems and distribution manifolds are utilized to connect multiple piping loops

Images courtesy IGSHPA
Manifold and Header Techniques

In-ground header systems are typically piped in one of three (3) distinct configurations:

1. **Reverse-Return** (preferred for balanced flow)

2. **Series** (generally avoided due to high pressure losses)

3. **Parallel or “Home run”** (each ground loop piped individually to a central header or manifold in a collection vault or in the building mechanical room or space)
Manifold and Header Techniques

Manifolds and Headers
- Example of typical Reverse-Return in-ground (buried) header system employing several pipe diameters to connect four (4) vertical boreholes; flow to be equal through all four borehole loops
- Connection details at tees and elbows not shown (not to scale)
Manifold and Header Techniques

Manifolds and Headers
- Example of typical Reverse-Return in-ground (buried) header system employing several pipe diameters to connect four (4) vertical boreholes; flow to be equal through all four borehole loops
Manifold and Header Techniques

Manifolds and Headers
- **Parallel distribution manifolds** (also called mechanical manifolds) are typically located in building mechanical spaces or in exterior collection vaults, buried in the earth.
- Typically contains a supply header and return header, mounted closely together in pairs.
- Manifolds may include shut-off and/or balancing valves.
- When the individual ground loops are connected to such a centralized distribution manifold, then the ground loops are in parallel, also known as **home-run**.
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Manifold and Header Techniques

Manifolds and Headers
- Example of a distribution manifold with shut-off valves on supply and return headers and balancing valves on supply header (two views of the same design)
Manifold and Header Techniques

Manifolds and Headers
- Example of HDPE collection vaults with integrated manifolds (two different designs)
Manifold and Header Techniques

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Manifold and Header Techniques

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4. PPI TN-55 and Other Resources

PPI TN-55 Content

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   3.1.2 Vertical Piping Systems
   3.1.3 Pipe-in-Pipe Coaxial Vertical Systems
   3.1.4 Helix Piping Systems
   3.1.5 Inclined or Angled Configurations
   3.1.6 Horizontal Directional Drilling (HDD)
   3.1.7 Energy Piles
   3.1.8 Submerged Piping Systems
4.0 Ground Loop Heat Exchange Piping Materials
5.0 Headers and Distribution Manifolds
6.0 Heat Transfer Fluid
7.0 Standards, Codes and Regulations
PPI TN-55 and Other Resources

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5.0 Headers and Distribution Manifolds
6.0 Heat Transfer Fluid
7.0 Standards, Codes and Regulations

PPI recommends that all HDPE piping components used for ground-coupled heat exchangers meet the requirements of industry standard ANSI/CSA/SHPE C448, and:

4.1.1 Be a high-density polyethylene extrusion compound with a pipe material designation code of PE 3608, PE 3691, PE 4710, and PE 4750, and a color and ultraviolet stabilizer code of C or E, per ASTM D3356.

4.1.2 Be listed as such by the Plastics Pipe Institute’s Hydrostatic Stress Board (HSSB) in PPI TR-4 with the minimum hydrostatic Design Stress (HDS) value of 300 psi at 73°F (22°C).

4.1.3 Meet the requirements of NSF/ANSI Standard 358-1.

4.1.4 Meet the requirements of NSF/ANSI Standard 61 for open-loop systems, or if the water supply or reservoir into which the piping system is installed is a water source for a potable water system.

See Table 1 for typical pressure ratings of some HDPE material grades and wall types.

Table 1: Minimum Pressure Ratings for Typical HDPE Geothermal Pipe

<table>
<thead>
<tr>
<th>PE Material</th>
<th>DR</th>
<th>Pressure (17°F)</th>
<th>Pressure (140°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE 3608</td>
<td>10</td>
<td>200 psi (1.4 MPa)</td>
<td>100 psi (0.7 MPa)</td>
</tr>
<tr>
<td>PE 3608</td>
<td>11</td>
<td>250 psi (1.7 MPa)</td>
<td>150 psi (1.0 MPa)</td>
</tr>
<tr>
<td>PE 3608</td>
<td>13.5</td>
<td>300 psi (2.1 MPa)</td>
<td>180 psi (1.2 MPa)</td>
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<tr>
<td>PE 4710</td>
<td>9</td>
<td>200 psi (1.4 MPa)</td>
<td>125 psi (0.8 MPa)</td>
</tr>
<tr>
<td>PE 4710</td>
<td>11</td>
<td>250 psi (1.7 MPa)</td>
<td>150 psi (1.0 MPa)</td>
</tr>
<tr>
<td>PE 4710</td>
<td>13.5</td>
<td>300 psi (2.1 MPa)</td>
<td>180 psi (1.2 MPa)</td>
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<tr>
<td>PE 4710</td>
<td>17</td>
<td>300 psi (2.1 MPa)</td>
<td>180 psi (1.2 MPa)</td>
</tr>
</tbody>
</table>

See also other PPI publications on PE materials, such as PPI’s Handbook of Polyethylene Pipe, Chapter 13 “HVAC Applications”.

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PPI TN-55 and Other Resources

PPI TN-55 Content

1.0 Introduction
2.0 Mechanical Components
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- Product information
- Technical Reports
- Case studies
- Design information
- Educational videos
- Finding Manufacturers
- Links to other organizations
- www.plasticpipe.org
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Plastic Pressure Piping Design Calculator
- Free online sizing tool at www.plasticpipecalculator.com

![Plastic Pressure Pipe Design Calculator](image)
Summary

This presentation:

1. Described the **plastic piping materials** used for ground source geothermal systems
   - HDPE  *high density polyethylene*
   - PEX  *crosslinked polyethylene*
   - PE-RT  *polyethylene of raised temperature resistance*
   - PP  *polypropylene (PP-R and PP-RCT)*

2. Discussed the industry **standards** that apply to these piping materials

3. Demonstrated various **manifold** and **header** techniques

4. Introduced **PPI TN-55** and other industry resources of piping information
Plastic Piping Materials for Ground Source Geothermal Systems

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