

PLASTIC PIPING MATERIALS FOR GROUND SOURCE GEOTHERMAL HEATING AND COOLING APPLICATIONS

PPI TN-55

2024



Foreword

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute (PPI). These members have shown their commitment to developing and improving quality products by assisting standards development organizations in the development of standards, and also by developing design aids and reports to help engineers, designers, code officials, specifying groups, contractors and users.

The purpose of this technical note is to provide information regarding the types of plastic piping materials used in ground-source geothermal/geoexchange heating and cooling applications, including various types of designs and installations, as well as information on appurtenances such as headers and manifolds.

The PPI has prepared this technical note as a service to the industry. The information in this document is offered in good faith and believed to be accurate at the time of its preparation but is offered “as is” without any express or implied warranty, including WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE. Additional information may be needed in some areas, especially with regard to unusual or special applications. Consult the manufacturer or material supplier for more detailed information. A list of member manufacturers is available on the PPI website. PPI does not endorse the proprietary products or processes of any manufacturer and assumes no responsibility for compliance with applicable laws and regulations.

PPI intends to revise this technical note within five years or sooner if required, from the date of its publication, in response to comments and suggestions from users of the document. Please send suggestions of improvements to the address below. Information on other publications can be obtained by contacting PPI directly or visiting our website.

For further information, contact: The Plastics Pipe Institute
105 Decker Court
Suite 825
Irving, Texas, 75062
469.499.1044
www.plasticpipe.org

This Technical Note, TN-55, was first issued in March 2018 and revised in August 2024.

Table of Contents

Table of Figures	4
List of Tables	4
1.0 INTRODUCTION	5
1.1. Categories of Geothermal Heating and Cooling Systems	6
2.0 MECHANICAL COMPONENTS	7
3.0 DEFINITIONS	7
4.0 GROUND-LOOP HEAT EXCHANGE SYSTEMS - GENERAL	10
4.1. Introduction to Ground Heat Exchanger (GHEX) Piping Systems	10
4.2. Geothermal Piping without Oxygen Diffusion Barriers	11
4.3. Ground-Loop Heat Exchange Piping Systems – Installation Types	11
4.4. Thermal Heat Transfer to the Ground	19
5.0 GROUND-LOOP HEAT EXCHANGE PIPING SYSTEMS - MATERIALS	19
5.1. HDPE: High-Density Polyethylene	20
5.2. PEX: Crosslinked Polyethylene	23
5.3. PE-RT: Polyethylene of Raised Temperature Resistance	24
5.4. PP: Polypropylene	25
6.0 HEADERS AND DISTRIBUTION MANIFOLDS	26
6.1. Header Systems Installed in the Ground	27
6.2. Distribution Manifold Systems	29
7.0 HEAT TRANSFER FLUIDS	31
8.0 STANDARDS, CODES, and REGULATIONS	32

Table of Figures

Figure 1a & 1b: Cross section of Single U-bend and Double U-bend Vertical heat exchangers.....	13
Figure 2: A cross section of a Coaxial heat exchanger (not to scale).....	15
Figure 3: Side-view of a Helix piping system heat exchanger (not to scale).....	16
Figure 4: Side-view of an Inclined piping system heat exchanger (not to scale)	16
Figure 5a & 5b: Coils of HDPE piping with molded HDPE U-bend already fused to pipe ends, also known as the U-bend assembly	21
Figure 6a & 6b: Coil of PEX Tubing and PEX continuous U-bend	23
Figure 7: Coil of PE-RT Tubing	24
Figure 8: Example PP-R and PP-RCT pipes and fittings.....	25
Figure 9: Typical step-up/step-down Reverse-Return in-ground (buried) header system employing several pipe diameters to connect six (6) vertical borehole heat exchangers; flow to be equal through all six. Connection details at tees and elbows not shown (not to scale).....	28
Figure 10a & 10b: 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)	29
Figure 11a & 11b: Examples of distribution manifolds with shut-off valves and balancing valves installed within mechanical rooms.....	30
Figure 12a & 12b: Examples of HDPE collection vaults with integrated manifolds (different designs)	31

List of Tables

Table 1: Thermal Conductivity Values of Piping Materials	19
Table 2: Temperature Compensating Multipliers for PE4710 Pipes.....	21
Table 3: Minimum Pressure Ratings for Typical HDPE Geothermal Pipe	22

PLASTIC PIPING MATERIALS FOR GROUND SOURCE GEOTHERMAL HEATING AND COOLING APPLICATIONS

1.0 INTRODUCTION

Ground source geothermal or geoexchange heating and cooling systems, also referred to as “geothermal exchange”, “ground source heat pumps”, “ground-coupled” or “earth energy” heat pump systems, are “...self-contained, electrically-powered systems that take advantage of the Earth's relatively constant, moderate ground temperature to provide heating, cooling, and domestic hot water more efficiently and less expensively than would be possible through other conventional heating and cooling technologies” according to IGSHPA¹, the *International Ground Source Heat Pump Association*.

Geothermal heat pumps are economical to operate and can significantly reduce heating and cooling operating costs over the life of the system. While a fossil-fuel burning appliance (e.g., furnace, boiler) typically delivers less than one unit of heat energy per unit of energy consumed, resulting in net efficiency of less than 100%, a ground source heat pump system (GSHP) typically delivers three to four units of heat energy per every unit of electricity consumed, resulting in net system efficiencies of 300% or greater when operating in heating mode. System efficiency can also be referred to as Coefficient of Performance or CoP, with the best water-to-water heat pump systems delivering CoP values greater than five. Many ground source heat pumps also generate domestic hot water.

At the time of publication of this document, the DOE webpage on Geothermal Heat Pumps (GHP)² states “The biggest benefit of GHP's is that they use 25% to 50% less electricity than conventional heating and cooling systems. This translates into a GHP using one unit of electricity to move three units of heat from the earth. According to the EPA, geothermal heat pumps can reduce energy consumption and corresponding emissions up to 44% compared with air-source heat pumps and up to 72% compared with electric resistance heating with standard air-conditioning equipment. GHPs also improve humidity control by maintaining about 50% relative indoor humidity, making GHPs very effective in humid areas.”

¹ igshpa.org

² energy.gov/energysaver/geothermal-heat-pumps

1.1. Categories of Geothermal Heating and Cooling Systems

The three primary categories of geothermal or geoexchange heating and cooling systems are commonly referred to as closed-loop, open-loop and direct-exchange:

- Closed-loop systems utilize plastic piping systems for the ground heat exchanger piping system (i.e., the “ground loop”) and are the primary focus of this technical note.
- Open-loop systems utilize ground water or surface water for the purpose of extracting or rejecting heat as the water is circulated through a mechanical heat pump. While open-loop systems utilize the types of plastic pipes included in this Technical Note, these systems are not the focus of this document.
- Direct-exchange systems utilize copper tubing embedded in the ground with refrigerant circulating directly within this buried copper tubing. These systems will not be addressed in this Technical Note.

1.1.1. Closed-Loop Geothermal Systems

Closed-loop geothermal systems utilize plastic pipes and fittings that are buried in the ground in a variety of configurations, or submerged in water. The network of pipe and fittings, sometimes referred to as the *ground heat exchanger*, or simply the *ground loop*, is usually connected to a mechanical fluid-source heat pump unit³.

The ground heat exchanger (GHEX) is the thermal energy source during heating cycles and the thermal sink during cooling cycles.

A basic closed-loop geothermal or geoexchange system typically includes:

- Mechanical Components: Mechanical heat pump with integrated electronic controls, circulating pumps and valves, typically installed indoors (see Section 2.0)
- Ground Heat Exchanger plastic pipe and fittings (see Section 5.0) which may be:
 - o Buried in a horizontal plane (e.g., trenches)
 - o Drilled in a vertical configuration (e.g., boreholes)
 - o Installed in a vertical large diameter hole (e.g., helix)
 - o Drilled or pushed into an angled configuration (e.g., inclined)
 - o Submerged in a surface body of water (e.g., pond, lake)
 - o Encased in structural building piling systems (e.g., energy piles)

³ In special circumstances, direct heat-transfer systems may be designed without a mechanical heat pump or with the ability to bypass the heat pump, whereby the same fluid that passes through the ground heat exchanger also passes through the hydronic distribution pipe (e.g., a radiant heating or cooling slab). The fluid is moved by an electrical circulating pump.

- Heat Transfer Fluid: Water or water/antifreeze solution (see Section 7.0)

This Technical Note will provide relevant information on each of these categories, with a focus on ground loop piping materials.

2.0 MECHANICAL COMPONENTS

Mechanical components (e.g., heat pumps, circulating pumps) should be designed and certified for closed-loop ground-coupled heating and cooling applications and meet the requirements of all applicable codes and regulations.

Water-to-air heat pumps are typically connected to ducted air distribution systems within a building.

Water-to-water heat pumps are typically connected to hydronic distribution systems within a building. A hydronic system is a heat distribution/absorption system in which the final heat-transfer medium is a fluid such as water. Examples include radiant heating, radiant cooling, baseboard radiators, panel radiators, fan-assisted convectors, and ducted fan coils which transfer the heat energy to and from the distribution air.

Many geothermal heat pumps also include desuperheater coils which can transfer thermal energy from the heat pump to generate domestic hot water. Some geothermal heat pumps (water-to-air or water-to-water) provide full condensing (100%) options for generating domestic hot water.

Water source heat pumps should be certified in accordance with

- AHRI/ASHRAE/CSA/ISO Standard 13256-1 for water-to-air heat pumps, and
- AHRI/ASHRAE/CSA/ISO Standard 13256-2 for water-to-water heat pumps.

Circulating pumps, often packaged as tandem units with integrated connections, fill ports, etc., also known as flow centers, are designed, built, and sized specifically for the ground loop network and heating/cooling loads of each geothermal system.

Certain circulating pumps use variable speed controllers which ramp the rotational speed of the pump motor up and down in response to increasing or decreasing heat exchange demands.

3.0 DEFINITIONS

Antifreeze: An additive used in water-based heat transfer fluids to decrease the freezing temperature of the fluid to protect piping systems against freezing

Borehole: a hole into the earth at any angle that is typically drilled, bored, cored, driven, hydraulically advanced, or otherwise constructed into the earth

Borehole heat exchanger: a borehole with a piping loop installed within for the purpose of exchanging heat with the earth

Closed-loop heat exchange system: a continuous, sealed, underground or submerged ground heat exchanger (i.e., ground loop) through which heat-transfer fluid (e.g., water plus antifreeze) passes to and returns from a heat pump

Electrofusion: a heat fusion joining process where the heat source is an integral part of the fitting, such that when an electrical current is applied, heat is produced that melts and permanently joins two or more plastic components (e.g., pipe and fitting)

Heat fusion: a method of joining two similar materials (e.g., HDPE-HDPE) by the application of heat to melt the mating surfaces and then pressing them together with sufficient force to become one monolithic piece

Ground heat exchanger (also known as ground loop, vertical loop ground heat exchanger, horizontal loop ground heat exchanger, submerged heat exchanger): a continuous, sealed, underground or submerged network of piping serving as the heat exchanger with the ground or water through which a heat-transfer fluid passes to and returns from a heat pump

Note 1: Ground heat exchangers may be vertically, diagonally, or horizontally configured or submerged in surface water.

Ground loop: the underground or submerged piping network of a ground loop heat exchanger through which the heat transfer fluid is circulated and thermal energy is exchanged with the earth

Ground source heat pump (GSHP) system: a heat pump system that is connected to a ground loop heat exchanger

Grout: a bentonite material or fluid mixture pumped into annular cavities between pipes and the earth to seal the cavity and conduct heat between the pipe and earth

HDPE: High-density polyethylene (pipe and fitting material)

Header: a pipe assembly that connects multiple parallel pipe circuits to supply or return piping; also called a “manifold”

Horizontal loop: an installation of ground heat exchanger piping that does not penetrate an aquifer and that can be inserted into a trench, open excavation, or installed by a horizontal directional drilling (HDD) method

Hydrostatic pressure: static pressure created by pressurizing a non-moving fluid inside a closed vessel, including pipes

IGSHPA: International Ground Source Heat Pump Association

Indoor piping: piping that is installed in geothermal system vaults or mechanical rooms and used to transition from buried ground loop piping to indoor mechanical systems. May include headers and manifolds when installed in indoor spaces. Sometimes referred to as “interior piping”

Open-loop (surface water or ground water) system: a network designed to utilize ground water or surface water for the purpose of exchanging thermal energy by circulation of the water through a mechanical heat pump

PEX: crosslinked polyethylene (piping material)

PE-RT: polyethylene of raised temperature resistance (piping material)

PP: polypropylene in one of two types known as PP-R and PP-RCT (piping material)

PP-R: polypropylene random copolymer

PP-RCT: polypropylene random copolymer with modified crystallinity & temperature resistance

Standard dimension ratio (SDR): a specific ratio of the average specified outside diameter to the minimum specified wall thickness (OD/t) for outside diameter-controlled plastic pipe, the value of which is derived by adding one to the pertinent number selected from the ANSI Preferred Number Series 10

Extracted, with permission, from ASTM F412 Standard Terminology Related to Plastic Piping Systems, copyright ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428. A copy of the complete standard may be obtained from ASTM International, www.astm.org

U-Bend assembly: a 180-degree directional change in a ground loop pipe, typically used at the bottom of a vertical borehole, that is fabricated or formed using a one-piece molded fitting attached to HDPE pipes via butt fusion, approved fittings for PE-RT or PEX pipe and tubing, or jointless hot-forming techniques

Vertical borehole: a vertical hole into the earth at any angle typically drilled, bored, cored, driven, hydraulically advanced, or otherwise constructed into the earth for the purpose of containing ground loop pipes for exchanging heat with the earth and not for the purpose of producing water

Vertical borehole heat exchanger: a vertical borehole with a piping loop installed within for the purpose of exchanging heat with the earth

4.0 GROUND-LOOP HEAT EXCHANGE SYSTEMS - GENERAL

The ground heat exchanger piping system (i.e., the ground loop) may be designed to supply the total heating and cooling capacity of the building for the specific geographical location, or for partial loads. Partial-load heating systems are often supplemented with heat sources such as boilers, or thermal solar collection systems. Partial-load cooling systems are often supplemented with mechanical chillers or cooling towers. In such situations, it is common for the geothermal system to be sized to carry a base building load, typically 75% to 85% of the peak load, and for the supplemental equipment to operate only when needed to meet peak loads.

4.1. Introduction to Ground Heat Exchanger (GHEX) Piping Systems

The piping material is critical to the overall success of the closed-loop ground heat exchanger and must provide corrosion resistance, chemical resistance, flexibility, impact resistance, resistance to slow crack growth, long-term hydrostatic strength (i.e., pressure capability), and temperature resistance. In addition, the ground loop heat exchanger materials must provide suitable heat transfer capabilities.

These piping systems may experience changes in pressure up to 60 psig (415 kPa), due to thermal expansion and contraction of the heat transfer fluid and the pipe itself over a potential operating temperature range from 25°F to 115°F (-4°C to 46°C).

Pressure and temperature cycles occur, to some degree, each time the system is operated. The typical average static pressure within the piping system at ground level is 25 psig to 40 psig (170 kPa to 275 kPa).

Recommended plastic piping materials for ground loops are:

- HDPE: High-density polyethylene
- PEX: Crosslinked polyethylene
- PE-RT: Polyethylene of raised temperature resistance
- PP: Polypropylene (for headers, manifolds, and indoor piping)

Each of these plastic piping materials provides important long-term performance benefits for geothermal applications, including:

- Flexibility
- Impact resistance
- Chemical resistance
- Corrosion resistance
- Temperature resistance
- Long-term hydrostatic strength (i.e., pressure capability)

While each of these materials shares common benefits for ground source geothermal applications, each material also has specific characteristics that influence their selection for various projects.

See Section 5.0 GROUND-LOOP HEAT EXCHANGE PIPING SYSTEMS - MATERIALS for additional information on these piping materials.

4.2. Geothermal Piping without Oxygen Diffusion Barriers

Some types of plastic piping materials are produced with a coextruded layer of an oxygen-tight material serving as an oxygen diffusion or permeation barrier layer. An oxygen barrier is typically required in closed loop heating systems with ferrous (i.e., containing iron or steel) components that could easily corrode when exposed to oxygenated water.

Unlike in closed-loop hydronic heating systems, where higher fluid temperatures and the presence of dissolved oxygen in the heating system fluid can cause corrosion of any ferrous components, geothermal ground loops operate at lower fluid temperatures where the diffusion of oxygen through the pipe wall and into the heating system fluid is negligible. Also, ground loop piping systems typically do not include exposed ferrous components that need protection against dissolved oxygen. In a geothermal exchange system, the ground loop piping is plastic, wetted surfaces of circulators are corrosion resistant (e.g., coated steel, bronze, or brass), and the portion of the coaxial heat exchanger within the heat pump that is exposed to the ground loop fluid is typically copper. Therefore, an integrated oxygen diffusion barrier layer is not recommended for ground loop piping. This recommendation also applies to headers and manifolds.

4.3. Ground-Loop Heat Exchange Piping Systems – Installation Types

Qualified designers should be involved with calculations and layouts for all ground-loop heat exchange system designs. Proper designs will determine the size and quantity of pipes which are required to meet design loads (typically expressed in BTU, kW, or Tons of energy) for a specific system.

Designers often use specialized software modelling programs to ensure that heat exchange capacities will be satisfied by the ground loop piping design, even modelling the heat exchange capabilities for several years of operation to avoid overheating or overcooling the earth over time.

For a given project, the selected type of installation can be affected by several factors, such as:

- Topography and geography of the land (type of soil, amount of overburden, hills, valleys, water table, etc.)
- The type of equipment available to the installer
- Accessibility for equipment
- Available land area
- Water table levels
- Proximity to body of water
- Local regulations
- Other factors