PLASTIC PIPING MATERIALS FOR GROUND SOURCE GEOTHERMAL HEATING AND COOLING APPLICATIONS

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Foreword

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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.

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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 IGSHPA[1], 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 unit[3].

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:
    - Buried in a horizontal plane (e.g., trenches)
    - Dropped in a vertical configuration (e.g., boreholes)
    - Installed in a vertical large diameter hole (e.g., helix)
    - Drilled or pushed into an angled configuration (e.g., inclined)
    - Submerged in a surface body of water (e.g., pond, lake)
    - 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 25ºF to 115ºF (-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

Ground-loop heat exchange piping system installation types include, but are not limited to, the following installation types:

4.3.1. Horizontal Loop Piping Systems

A horizontal loop piping system is typically buried at depths of 4 to 7 feet (1.2 to 2.1 m) within trenches, usually below the frost line for the location. Pipe spacing and positioning depends on factors such as soil type, thermal conductivity of the soil, width of the trench, and other factors. Trench width can vary from just 2 ft. to 8 ft. (0.6 to 2.4 m) or more, depending upon factors such as the topography, soil type, equipment availability, etc. The number of pipes and spacing between pipes installed within trenches can also vary.

Trench safety during installation of the pipe is an important consideration when designing trenches and local regulations must be adhered to (e.g., OSHA trenching and excavation safety requirements in 29 CFR 1926.651 and 1926.652).

Note 2: Embedment and backfill materials and procedures are critical to long-term durability of buried pipes. ASTM D2774 S*tandard Practice for Underground Installation of Thermoplastic Pressure Piping* is the general guideline for proper installation of buried plastic pipes and contains definitions of embedment and backfill materials and layers.

4.3.2. Vertical Piping Systems

For vertical systems, flexible plastic pipes can be fabricated or formed into U-bend assemblies using fused joints, mechanical fittings or jointless hot-forming techniques. U-bend assemblies are lowered into vertical boreholes, and then grouted[4] from the bottom to the top of the borehole with a grouting material selected for factors such as safety for contact with water aquifers, thermal conductivity, pumpability, non-permeability, and other environmental factors.

Note 3: U-bend assemblies should be factory-fabricated and not assembled on the jobsite.

Typical borehole heat exchanger depths range from 50 to 1,000 feet (15 m to 305 m), and even deeper in certain projects using improved drilling technology.

[4] Grout is a bentonite material or fluid mixture pumped into annular cavities between pipes and the earth to seal the cavity. Grout material is usually mixed onsite and pumped into the borehole from the bottom to the top using an open-ended pipe known as the Tremie pipe. The functions of grout are: protection of groundwater supply; to prevent groundwater migration between aquifers; for heat transfer between pipes and borehole walls; and to prevent upward leakage from aquifers. Proper grout materials allow movement of the pipes and do not shrink or create voids. Approved grout materials and their placement are typically controlled by local/state/provincial regulations.

In some cases, vertical boreholes may extend into or through water aquifers that serve as sources for residential or municipal potable water systems. For this reason, pipes must be certified to NSF/ANSI/CAN 61 for drinking water safety.

Both single U-bend and double U-bend configurations are available. Double U-bends can increase the thermal performance of a borehole heat exchanger. See **Figures 1a & 1b**.

Note 4: The diameter of the borehole is selected on factors such as the soil formation and stability, the size of the U-bend assembly, available equipment, and other factors. Borehole diameters must be large enough to allow the placement of the U-bend assembly and the tremie pipe for grout placement. However, a borehole diameter that is larger than necessary will require more drilling, more excavation of material, and more grout, and may result in lower thermal conductivity due to greater distance between the heat transfer pipes and the soil formation.

Note 5: Heat of hydration is the heat released when water reacts with cement powder; this is an exothermic chemical reaction that generates heat as the mixture cures. Certain grout mixtures containing cement can reach temperatures above 120°F (49°C) for short periods of time during curing. Since plastic pipes used for borehole heat exchangers are encased within the grout, there is the possibility for the internal pressure within these pipes to exceed their pressure ratings at these elevated temperatures. See **Table 2** for Temperature Compensating Multipliers for PE4710 pipes.

Although reported instances of this temperature exposure causing failure of HDPE pipes is rare, such exposure is to be prevented by controlling the grout mixture to limit the heat of hydration during curing and by limiting the pressure within the pipes during the elevated temperature exposure. To help protect pipes against excessive temperatures, cold water may be flushed through the pipes during the curing of the grout at a flow rate which will allow the water to absorb the excessive heat of hydration; this water may be drawn from a large reservoir which can absorb the thermal energy, or the water can be dumped and constantly replaced to control the temperature within the pipes during the curing time period.

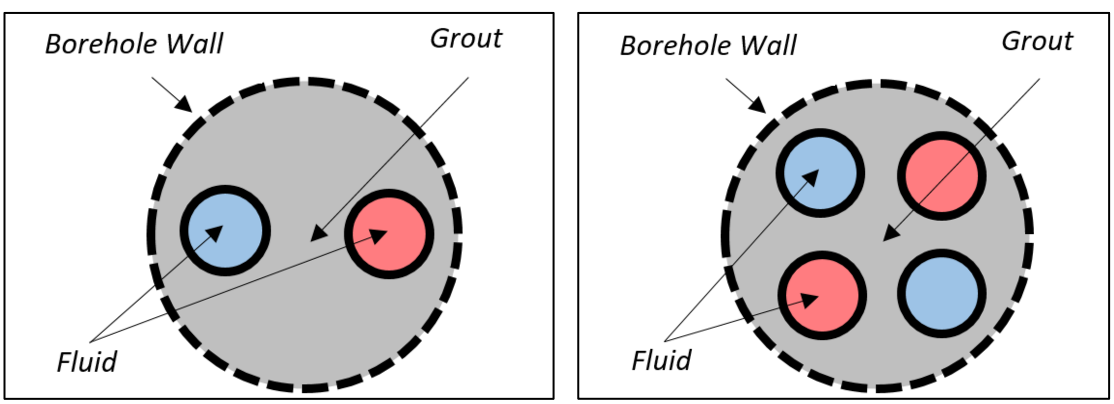

Figure 1a (left) & 1b (right): Cross section of Single U-bend and Double U-bend Vertical heat exchangers

4.3.2.1. Effects of borehole depth on pipe pressure

The pressure inside pipes that is caused by elevation is known as static water column pressure. Static water column pressures in vertical borehole heat exchange piping systems are increased with the depth of the borehole and the height of the building above grade, if not hydraulically-separated and should be considered when selecting the piping material, its wall type (i.e., dimension ratio or DR), and its pressure rating to prevent exceeding the internal pressure rating (IPR) of the pipe when installed in a borehole.

For example, using a density for water of 62.4 lbs per ft^3 at 40°F (4°C) ÷ 144 in^2/ft^2 = 0.433 lbs/in^2 or 0.433 pounds per square inch of added internal pressure per 1 ft of water height. 10 feet of water elevation creates 4.3 psi static water column pressure inside piping systems, and 2.307 feet of water elevation creates 1 psi. Antifreeze fluids added to water (e.g., methanol, glycol) can have different densities and will result in different hydrostatic pressures.

Designers should calculate the static water column pressure in vertical borehole installations and ensure that pressure ratings of pipes are not exceeded.

In a properly grouted borehole heat exchanger, the pressure of the grout surrounding the pipe will balance the static pressure of the fluid inside. In some installations, pipes pass through an aquifer, in which case the water surrounding the pipe balances the static pressure of the fluid inside.

The PPI **Plastic Pipe Design Calculator** at www.plasticpipecalculator.com includes a function to help estimate the Static Water Column Pressure in a geothermal vertical borehole heat exchanger. This Calculator can also be used to estimate the pressure loss through plastic piping materials as well as the volume of various types and diameters of piping materials. This function may also be used to estimate antifreeze quantities.

4.3.2.2. Prevention of Hydrostatic Buckling or Collapse

When external pressure is applied to the outer wall of cylinder, there is the possibility of buckling or collapse of the cylinder. A pipe can be considered a cylinder in this regard.

For plastic pressure pipe and tubing materials that are installed within deep vertical boreholes, there is the theoretical possibility that external pressure caused by grout or groundwater on the outside of pipes could cause unconstrained pipe buckling or collapse. The term “unconstrained” is used when pipes are not surrounded with compacted backfill, as is the case in a borehole heat exchanger.

Extensive industry experience has provided the mathematical models to predict when such buckling could occur, allowing designers and installers to prevent such occurrences.

The calculation methods presented in the PPI *Handbook of Polyethylene Pipe* (Chapter 6) or in the ASHRAE *HVAC Applications Handbook* (Chapter 35, Geothermal Energy) may be used to illustrate that the installation process does not exceed pipe pressure or buckle/collapse resistance ratings.

4.3.3. Pipe-in-Pipe Coaxial Vertical Systems

Instead of placing two vertical pipes adjacent to each other connected with a U-bend assembly at the bottom of the borehole, a pipe-in-pipe coaxial vertical system utilizes one pipe inside a larger vertical pipe in a concentric arrangement. See **Figure 2**.

There are several configurations available for this type of installation, but the objective is to improve the thermal performance of a vertical borehole heat exchanger by increasing the surface area of the external larger coaxial pipe, and therefore, reducing borehole thermal resistance of heat transfer from the ground to the pipe's surface. Installation techniques are different, as compared to the continuous pipe loops typically used in vertical boreholes, and borehole diameters may need to be larger to accommodate the external pipe.

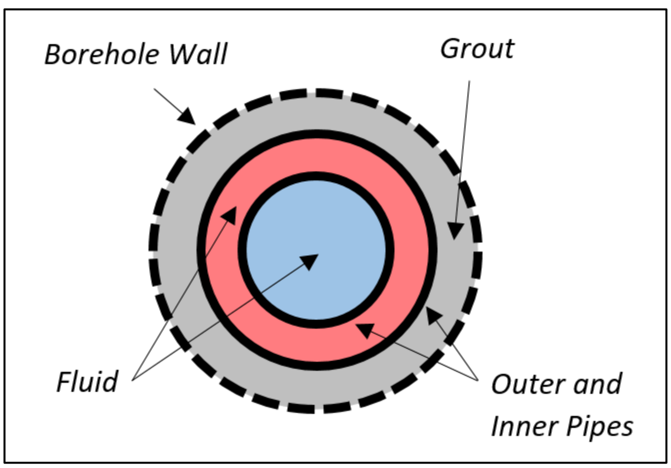

Figure 2: A cross section of a Coaxial heat exchanger (not to scale)

4.3.4. Helix Piping Systems

Certain project sites are neither ideal for horizontal systems nor traditional vertical borehole heat exchangers, but may be suitable for helix piping systems. A helix system uses a wide borehole which is augured into the ground, typically 2 to 3 feet (0.6 to 0.9 m) in diameter and 16 to 20 ft. (4.9 to 6.1) deep. After the hole is dug, a tightly wound coil of pipe in a helix configuration is stretched-out into the hole.

Normally, the pipe is backfilled with native soil mixed with water for natural compaction. No grouting is used. Helix piping systems may be suitable where there is up to 20 ft. (6.1 m) of loose overburden (e.g. soil) above a rocky substrate, or where environmental regulations or other technical factors restrict drilling traditional boreholes deeper than 20 ft., for instance. See **Figure 3**.

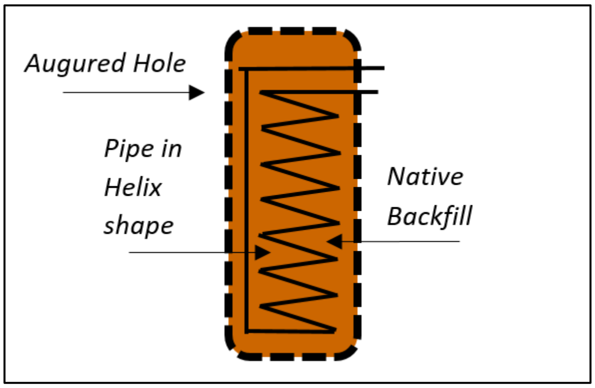

Figure 3: Side-view of a Helix piping system heat exchanger (not to scale)

4.3.5. Inclined or Angled Configurations

For project sites that may have limited access at the ground surface for multiple vertical borehole heat exchangers, inclined or angled configurations involve drilling several intentionally non-vertical boreholes at angles from a common entry point or nearby entry points. Some installers have innovated hydraulic ram devices that, in certain soft soil conditions, will push piping U-bend assemblies into the earth without predrilling boreholes. This process avoids grouting requirements, as the native soil reinstates itself around the heat exchange pipes. The pushing of the pipes from a common entry point may be done at various inclined angles. See **Figure 4**.

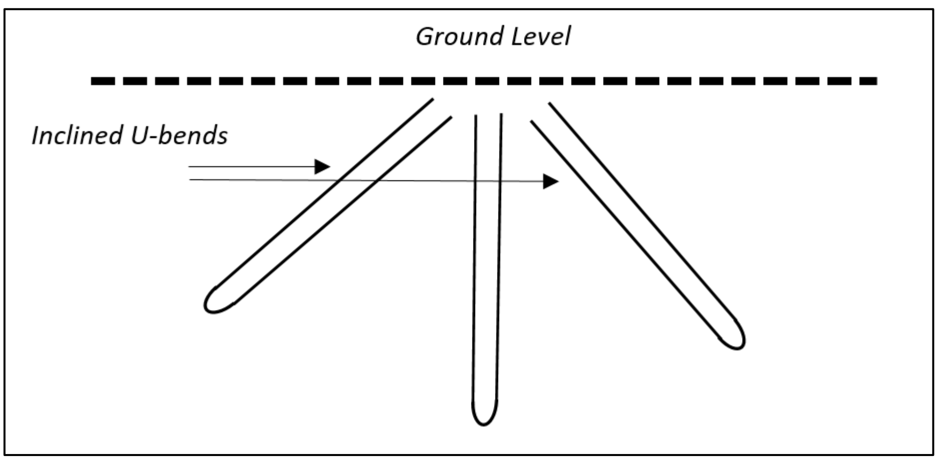

Figure 4: Side-view of an Inclined piping system heat exchanger (not to scale)

4.3.6. Horizontal Directional Drilling (HDD)

Horizontal Directional Drilling (HDD) is a technique for installing various types of pipes below ground using a surface-mounted drill rig that launches and places a drill string at a shallow angle to the surface and has tracking and steering capabilities.

The drill string creates an initial (pilot) borehole of several inches diameter in an essentially horizontal path or shallow arc which may be enlarged during a secondary operation, or sequence of such operations, through use of a reamer.

The predetermined path of the bore is maintained by tracking the path of the pilot bore using a manually operated overhead receiver or a remote (wireline or wireless) tracking system and performing steering and path corrections by controlling the orientation of the drill head. Soil penetration is accomplished using high pressure, low volume fluid jets and/or mechanical cutting. The drilling fluid serves several purposes, including stabilization of the borehole, removal of cuttings, lubrication for the drill string and product pipe, and cooling the drill head and transmitter electronics.

Typically, the resultant slurry created by the combination of the drilling fluid and soil cuttings gradually solidifies into a solid mass encapsulating the product pipe.

Plastic ground loop pipe is typically installed during the final reaming operation, or, if necessary, as a separate last step in the process.

Horizontal directional drilling can be suitable for geothermal ground loop pipes and allows horizontal placement of the pipes at depths greater than open trenching, without disruption of the surface. Depending on soil types and the installer preference, plastic pipes can be installed individually and then connected where exposed at ground level (or in pits). Also, ground loops with integrated U-bend assemblies (fused, formed, or permanent mechanical attachments), may be installed together in one horizontal borehole.

Note 6: See PPI TR-46 *Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of High Density Polyethylene Pipe* for more information on horizontal directional drilling.

4.3.7. Energy Foundations (Piles)

A pile or piling is a vertical structural element of a deep foundation, driven or drilled deep into the ground at a building site, used to transfer the weight of a building to solid earth. Piles are often used where the top layer of soil cannot support the weight of a building. Depths can range from 20 to 150 ft. (6 to 45 m).

Typically used in larger commercial applications where structural pilings are used for building support, geothermal pipes are sometimes installed within structural pilings to exchange thermal energy with the surrounding earth. The geothermal heat exchange pipes are fastened to structural steel rebar in circular or vertical patterns before the steel rebar “cages” are dropped into the holes. The concrete around the steel transfers the weight of the building to the earth and helps to exchange heat from the embedded plastic pipes with the surrounding earth.

4.3.8. Submerged Piping Systems

In submerged piping systems, the piping network is submerged in a body of water (e.g., lake, pond, large tank, or seawater) that is capable of handling the thermal rejection and extraction load of the application. Since the density of plastic piping materials is slightly less than water, the piping system must be weighted with ballast to overcome its buoyancy and prevent floating and to hold it on or near the bottom of the body of water. Pipes used in these installations should be installed deep enough to avoid water that is subject to freezing.

Care must also be taken that sediment, silt, or growths such as algae do not cover the pipes, as this would reduce heat transfer to the surrounding body of water. The body of water may, in some cases, also be the water source for a public or private water system.

Prior to design of any geothermal system, consult local/state/provincial regulations which may dictate or prohibit certain types of installations, including the depth of excavating or drilling, borehole design (e.g., diameter), casing requirements for some vertical systems, the type of pipe permitted for use, and grouting requirements, such as the depth of grout required, and the type of grout permitted for use.

Industry standards, codes and local/state/provincial regulations will require all below-grade connections to be joined using heat fusion or approved mechanical fittings. The designer and installer should be knowledgeable of and proficient in the joining procedures recommended by the pipe and fittings manufacturer.

Industry standards, codes and local/state/provincial regulations will often specify which types of heat transfer fluid/s are permitted for use in the specific jurisdiction or location.

Note 7: See Section 7.0 HEAT TRANSFER FLUIDS for more information on fluids.

4.4. Thermal Heat Transfer to the Ground

The thermal heat transfer between buried pipe and the ground is governed by the basic equation:

$$q = (k\,A/x)\,(T_1 - T_2)$$

Where:
q = Heat loss, BTU/hr
k = Thermal conductivity, BTU-in/ft^2-hr-°F
A = Heat transfer area, ft^2
x = Wall thickness, inches
T_1 = Outside temperature, °F
T_2 = Inside pipe temperature, °F

However, the above equation only addresses the question of conductive heat transfer through the pipe wall at steady-state conditions. Depending on the application (ground source heat exchange, snow melting, radiant heating, etc.) there are other factors that may have a significant influence on the accuracy of the heat transfer calculation, including the thermal conductivity of the surrounding embedment material (e.g., soil, grout, concrete, or water), the inside and outside film coefficients of the pipe, and perhaps others.

Therefore, it is recommended that such calculations should be referred to engineers with expertise in this field. See **Table 1** for Thermal Conductivity values for HDPE, PEX, and PE-RT.

Table 1: Thermal Conductivity Values of Piping Materials

Piping Material	Specific Heat Btu/lb-°F	Thermal Conductivity Btu-in/hr-ft^2-°F
PE4710	0.46	3.1
PEX	-	2.9
PE-RT	0.46	3.1

5.0 GROUND-LOOP HEAT EXCHANGE PIPING SYSTEMS - MATERIALS

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.

The following plastic piping materials for ground loops are described below:

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

Each of these piping materials delivers long-term reliability proven over decades of use around the world. 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. Relevant product standards are listed within Section 8.0 STANDARDS, CODES and REGULATIONS.

Long-term pressure ratings for these piping materials are developed based on testing in accordance with **ASTM Test Method D2837**, and piping materials are listed according to **PPI TR-3**. While materials such as PE4710 have projected design life of 100 years or more in municipal water applications, ground source geothermal applications have more variables in system operation (e.g., temperature and pressure), so PPI conservatively reports that the life expectancy of these plastic piping materials, when specified correctly and installed according to industry and manufacturers' guidelines, is typically well in excess of fifty (50) years.

PPI MS-7 *Model Specification for Plastic Piping Materials for Ground Source Geothermal Applications* contains detailed specifications for each of the piping materials listed in this document plus details on fitting types, installation methods and procedures, pressure testing procedures, and more.

5.1. HDPE: High-Density Polyethylene

High density polyethylene (HDPE) is a plastic resin made by the copolymerization of ethylene and a small amount of another hydrocarbon. The resulting base resin density, before additives or pigments, is greater than 0.941 g/cm^3. HDPE is a tough, durable piping material with unique performance properties that allow for its use in a broad range of applications, utilizing a variety of different construction techniques.

HDPE is the most common type of piping material used for ground heat exchangers with decades of proven service for this application. It is recognized in virtually all codes and standards as an approved material for ground heat exchange piping systems. See **Figure 5.**

HDPE pipe and tubing are available in several standard dimension ratios (SDRs) or wall thicknesses, and are typically joined with HDPE fittings using one of three heat fusion methods: butt fusion, socket fusion, or electrofusion.

Figure 5a (left) & 5b (right): Coils of HDPE piping with molded HDPE U-bend already fused to pipe ends, also known as the U-bend assembly

The pressure rating (PR) for thermoplastic plastic pipe material reduces with increased operating temperature. See **Table 2** for Temperature Compensating Multipliers for PE4710 pipes which should be applied to the pressure rating of a PE4710 pipe that is to be operated at the temperature ranges shown in the table.

Table 2: Temperature Compensating Multipliers for PE4710 Pipes

PE4710 Operating Temperature	Temperature Compensating Multiplier
≤ 80°F	1.0
> 80°F – 90°F	0.9
> 90°F – 100°F	0.8
> 100°F - 110°F	0.8
> 110°F - 120°F	0.7
> 120°F - 130°F	0.7
> 130°F - 140°F	0.6

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

1. Be a high-density polyethylene extrusion compound with a pipe material designation code of PE4710 and a color and ultraviolet stabilizer code of C or E, per ASTM D3350. Code E compounds shall be stabilized against deterioration from unprotected exposure to ultraviolet (UV) rays for not less than 3 years as evidenced by meeting the test criteria specified in AWWA C901;
2. Be listed as such by the Plastics Pipe Institute's Hydrostatic Stress Board (HSB) in PPI TR-4 with the minimum Hydrostatic Design Stress (HDS) value of 800 psi at 73°F (23°C);
3. Be certified to the requirements of ASTM D2737, ASTM D3035, ASTM F714, or CSA B137.1;
4. Be certified to the requirements of NSF/ANSI 358-1; and
5. Be certified to the requirements of NSF/ANSI/CAN 61.

See **Table 3** for typical pressure ratings of some HDPE material grades and wall types.

Table 3: Minimum Pressure Ratings for Typical HDPE Geothermal Pipe

PE Material	SDR	Pressure rating @ 73°F	Pressure rating @ 140°F
PE4710	9	250 psi (1.7 MPa)	160 psi (1.1 MPa)
PE4710	11	200 psi (1.4 MPa)	125 psi (0.9 MPa)
PE4710	13.5	160 psi (1.1 MPa)	100 psi (0.7 MPa)
PE4710	17	125 psi (0.9 MPa)	80 psi (0.6 MPa)

Note 8: For more information about HDPE pipe properties, see the PPI *Handbook of Polyethylene Pipe*.

Note 9: For specific language regarding specifying HDPE piping systems for geothermal applications, including information on fittings, joining, and installation, please see PPI MS-7 *Model Specification for Plastic Piping Materials for Ground Source Geothermal Applications.*

5.2. PEX: Crosslinked Polyethylene

Crosslinked polyethylene (PEX) is a polyethylene material which has undergone a change in molecular structure using a chemical or a physical process whereby the polymer chains are chemically linked. Crosslinking of polyethylene into PEX for pipes results in improved properties such as elevated temperature strength and performance, chemical resistance, and resistance to slow crack growth.

PEX is a high-temperature, flexible pressure pipe first introduced in Europe in the early 1970s and has since delivered over fifty years of successful use around the world, including extensive testing for durability and material performance. It was introduced into North America in the early 1980s and is widely used for plumbing, water service, fire protection, hydronic heating and cooling, snow and ice melting and ground source geothermal piping systems. See **Figure 6.**

Figure 6a (left) & 6b (right): Coil of PEX Tubing and PEX continuous U-bend

PPI recommends that all PEX tubing components used for ground heat exchangers meet the requirements of industry standard CSA/ANSI/IGSHPA C448 and:

1. Be a crosslinked polyethylene compound with a pipe material designation code of PEX 1206[5], PEX 1306, PEX 3206, PEX 3306, PEX 5206 or PEX 5306 per ASTM F876 and CSA B137.5;
2. Be listed as such by the Plastics Pipe Institute's Hydrostatic Stress Board (HSB) in PPI TR-4 with a minimum Hydrostatic Design Stress (HDS) value of 630 psi and a minimum pressure rating of 160 psi (1,100 kPa) at 73°F (23°C);
3. Be certified to the requirements of ASTM F876 or CSA B137.5;
4. Be certified to the requirements of NSF/ANSI 358-3; and
5. Be certified to the requirements of NSF/ANSI/CAN 61.

[5] PEX 1206 meets the minimum requirements of CSA/ANSI/IGSHPA C448 and other model codes. Other PEX material designation codes listed exceed the minimum requirements.

Note 10: PEX compounds will also be listed by PPI's Hydrostatic Stress Board with a minimum Hydrostatic Design Basis (HDB) value of 800 psi at 180°F (82°C).

See also other PPI publications on PEX materials, such as PPI TN-17 Crosslinked Polyethylene Pipe & Tubing.

Note 11: For specific language regarding specifying PEX tubing systems for geothermal applications, including information on fittings, joining, and installation, please see PPI MS-7 *Model Specification for Plastic Piping Materials for Ground Source Geothermal Applications.*

5.3. PE-RT: Polyethylene of Raised Temperature Resistance

Polyethylene of raised temperature resistance (PE-RT) is a polyethylene (PE) resin in which the molecular architecture has been designed such that a sufficient number of tie chains are incorporated to allow operation at elevated or raised temperatures (RT). Tie chains "tie" together the crystalline structures in the polymer, resulting in improved properties such as elevated temperature strength and performance, chemical resistance, and resistance to slow crack growth.

PE-RT is a high-density polyethylene material with enhanced capabilities to withstand higher temperatures. PE-RT tubing was first introduced in Europe in the 1980s and has since delivered over forty years of successful use around the world with extensive testing for durability and material performance. It was first introduced into North America in 2003. See **Figure 7.**

Figure 7: Coil of PE-RT Tubing

PPI recommends that all PE-RT tubing components used for ground heat exchangers meet the requirements of industry standard CSA/ANSI/IGSHPA C448 and:

1. Be a high-density polyethylene extrusion compound with a pipe material designation code of PE3608[6] or PE4710 and a color and ultraviolet stabilizer code of C or E per ASTM D3350 or ASTM F2769;
2. Be listed as such by the Plastics Pipe Institute's Hydrostatic Stress Board (HSB) in PPI TR-4 with the minimum Hydrostatic Design Stress (HDS) value of 630 psi at 73°F (23°C) and a minimum pressure rating of 160 psi (1,100 kPa) at 73°F (23°C);
3. Be certified to the requirements of ASTM F2769 or CSA B137.18;
4. Be certified to the requirements of NSF/ANSI Standard 358-4; and
5. Be certified to the requirements of NSF/ANSI/CAN Standard 61.

Note 12: A PE-RT compound will also be listed by PPI's Hydrostatic Stress Board with a minimum Hydrostatic Design Basis (HDB) value of 630 psi at 180°F (82°C) instead of the typical 140°F (60°C) HDB listings for HDPE compounds.

Note 13: For specific language regarding specifying PE-RT tubing systems for geothermal applications, including information on fittings, joining, and installation, please see PPI MS-7 *Model Specification for Plastic Piping Materials for Ground Source Geothermal Applications.*

5.4. PP: Polypropylene

Polypropylene (PP) is a versatile piping material that is used in a wide range of applications, including high-temperature pressure piping. Two types of PP are used for pressure piping systems: polypropylene random copolymer (PP-R) and polypropylene random copolymer with modified crystallinity and temperature resistance (PP-RCT). PP-R and PP-RCT are copolymers of propylene and at least one comonomer, where the propylene is more than 50% of the composition. See **Figure 8.**

Figure 8: Examples of PP-R and PP-RCT pipes and fittings

[6] *PE 3608 meets the minimum requirements of CSA/ANSI/IGSHPA C448 and other model codes. PE4710 material exceeds the minimum requirements.*

PP-R was first used for plumbing and hydronic heating in the 1980s in Europe and introduced into North America in the early 2000s. PP-RCT was introduced to North America several years later. PP-R and PP-RCT materials are included in the same product standards and are suitable for indoor piping, headers, and manifolds in geothermal applications.

PPI recommends that all PP piping components used for ground heat exchangers meet the requirements of industry standard CSA/ANSI/IGSHPA C448 and:

1. Have a Minimum Required Strength (MRS) of 10 MPa (1,450 psi) at 20°C (68ºF) per ISO 9080;
2. Be certified to the requirements of ASTM F2389 or CSA B137.11 and be approved by the manufacturer for ground source heat pump applications;
3. Be certified to the requirements of NSF/ANSI 358-2; and
4. Be certified to the requirements of NSF/ANSI/CAN 61 for open-loop systems, or if the water aquifer or reservoir into which the piping system is installed is a water source for a potable water system.

Note 14: For specific language regarding specifying PP tubing systems for geothermal applications, including information on fittings, joining, and installation, please see PPI MS-7 *Model Specification for Plastic Piping Materials for Ground Source Geothermal Applications.*

The piping materials listed in Sections 5.1, 5.2, 5.3, and 5.4 are based on the requirements of product standards and model codes (i.e., mechanical and geothermal codes) used within USA and Canada. Requirements for piping materials used for geothermal systems in each city, county, state/province or other countries (e.g., Mexico) may differ from the requirements listed within this Technical Note to comply with local regulations.

6.0 HEADERS AND DISTRIBUTION MANIFOLDS

Most ground source geothermal projects require more than one loop of ground heat exchanger piping or other style of heat exchanger in the ground for the required heat transfer capacity. This means that for most installed systems, there are multiple horizontal loops, borehole heat exchangers, helixes, energy piles, pond loops, etc. Geothermal ground loop systems can range in size from just a few ground heat exchangers (i.e., pipe loops) to hundreds or even thousands of U-bend assemblies.

Header systems and distribution manifolds are utilized to connect the various piping loops and to transport fluid to and from the heat pump. As described in this document, headers and distribution manifolds are somewhat distinct from each other. Headers are typically buried in the ground and have no valves for flow control of the individual ground loops (i.e., valveless), whereas distribution manifolds typically have valves for flow control and/or isolation of individual ground loops and are mounted inside access vaults or indoor mechanical rooms.

Common materials for headers and distribution manifolds include:

- HDPE: Using the same materials for pipes and fittings which are heat-fused together using reducing tees for direct burial in the ground.
- PP: Fabricated on-site or in a factory setting with reducing tees fused onto larger main pipes; valves of the same PP material may be fused into each outlet for control of each loop, or manifolds may be valveless
- Steel or stainless steel[7]: Fabricated in a factory setting with reducing tees welded onto larger main pipes
- Copper or copper alloy[7] (e.g., brass): Fabricated in a factory setting with outlets joined onto larger headers using threaded or brazed connections

Sections 6.1 and 6.2 will describe headers and distribution manifolds in detail.

6.1. Header Systems Installed in the Ground

The term "header" generally refers to piping configurations that are buried below grade in the earth. Headers may be fabricated in the field using sections of pipes joined to tees and elbows or may be partially prefabricated in a factory before installation at the project site and then buried directly in the ground.

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

- Reverse-Return (preferred for balanced flow); or
- Series (generally avoided due to high pressure losses); or
- 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).

Valveless in-ground (buried) headers often require designers to employ several pipe diameters in a step-up/step-down Reverse–Return layout, stepping-up and stepping-down pipe diameters to direct the fluid flow to be equal to all ground loops, otherwise short circuits can result. Short circuits will receive excessive flow, simultaneously drawing flow from other longer circuits, resulting in an unbalanced system that likely will not meet performance expectations over time. See **Figure 9** as an example.

[7] Distribution manifolds or headers constructed of steel or copper alloy (brass) components must be carefully selected and are usually not appropriate to be buried in direct contact with the soil due to risk of corrosion. Common techniques for protecting the metal components from naturally corrosive soil and/or damaging chemicals in the soil may include housing the manifold or header in a buried vault or wrapping the metal components with self-fusing, silicone tape.

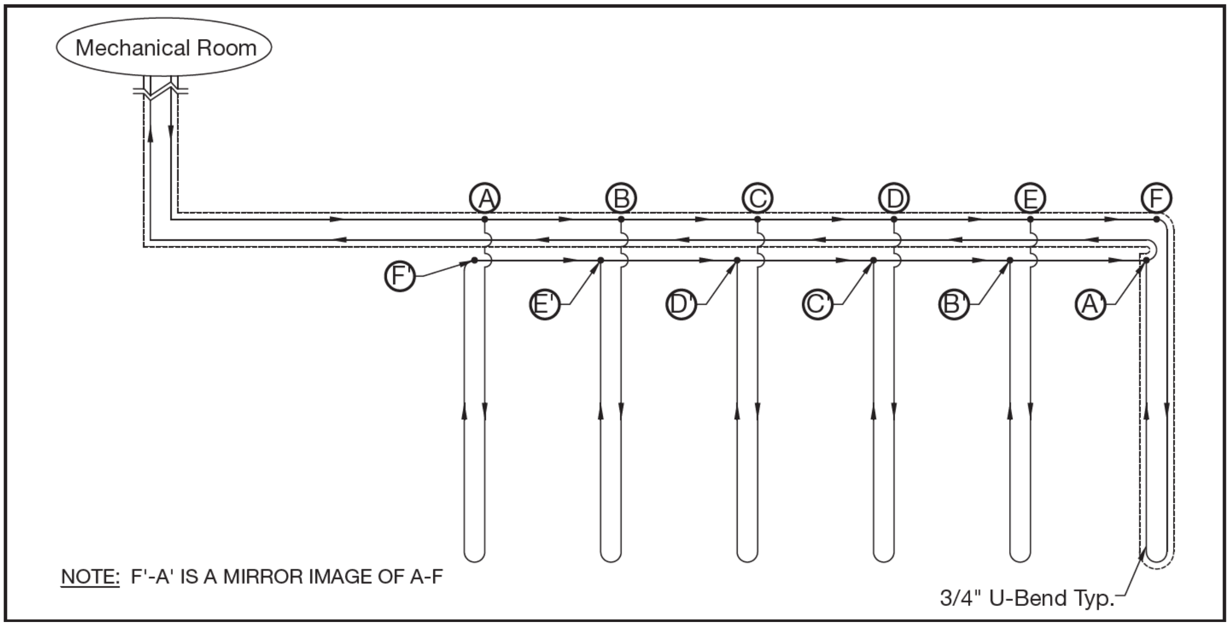

Figure 9: Typical step-up/step-down Reverse-Return in-ground (buried) header system employing several pipe diameters to connect six (6) vertical borehole heat exchangers; flow to be equal through all six. Connection details at tees and elbows not shown (not to scale).

The step-up, step-down pipe diameters provide an assembly called a reducing header, which is critical when purging air from the system. Non-reducing headers require significantly higher flow rates to achieve sufficient velocity (at least 2 feet per ssecond) through each parallel circuit. Depending upon the number of circuits, systems with non-reducing headers may be nearly impossible to purge air from the piping system adequately due to the inability to achieve sufficient velocity in each of the parallel circuits.

When using valveless headers buried in the ground, designs that balance flows through individual loops or ground heat exchangers are critical. Systems with loop lengths that differ more than 10% in total length from each other may result in unbalanced flows and poor performance, unless other balancing techniques are employed.

Unbalanced header systems or header systems with a large number of connected individual ground loops can present significant challenges when filling the system with fluid and purging of air. This process often requires specialized high-head and high-volume purging equipment to be used on-site temporarily for this purpose. It is recommended to limit the number of loops (i.e., circuits) or U-bend assemblies per header to help with filling, purging, testing, and the potential for isolation, if needed.

6.2. Distribution Manifold Systems

Distribution manifolds (also called mechanical manifolds) are typically located in building mechanical spaces or in exterior collection vaults, buried in the earth. A distribution manifold typically contains a supply header and a return header mounted closely together in pairs. When the individual ground loops are connected to a centralized distribution manifold, then the ground loops are in parallel, also known as *home run*.

Larger pipes transfer fluid to and from the supply and return headers of the distribution manifold, respectively, to the heat pump equipment in the mechanical room or space.

Distribution manifolds may be built with individual balancing valves installed on the supply or return header, depending on the type of balancing valve used.

Balancing valves can correct the unbalanced pressure loss (or head loss) of short circuits simply by adding the correct amount of resistance in the valve itself. This can correct inherently unbalanced systems to ensure optimal flow through each loop of the ground heat exchanger piping. See **Figures 10** and **11** as an examples.

Shut-off valves are typically installed at each loop or circuit, on both supply and return headers, to allow for complete isolation for purging, repair and maintenance.

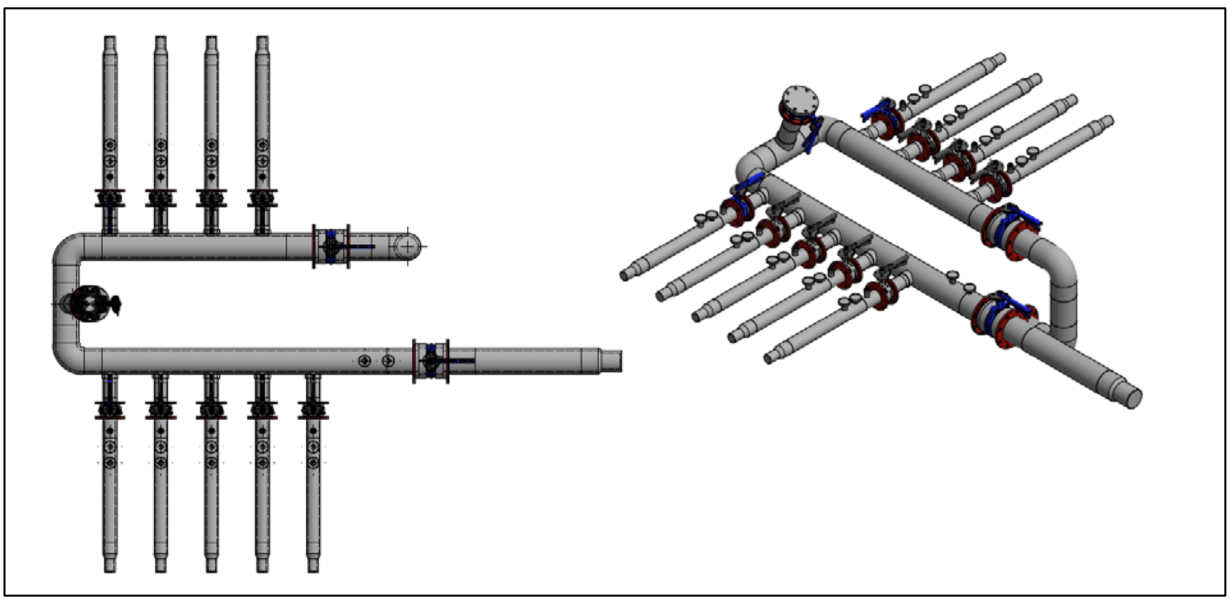

Figure 10a (left) & 10b (right): Example of a distribution manifold with shut-off valves on supply and return headers and balancing valves on supply header (two views of the same design)

Figure 11a (left) & 11b (right): Examples of distribution manifolds with shut-off valves and balancing valves installed within mechanical rooms

6.2.1. <u>Collection Vaults</u>

Underground collection vaults are generally employed when the mechanical space in the building is limited, or the ground loop system is far from the building. Exterior buried collection vaults can be located adjacent to buildings or installed at long distances from buildings, oftentimes hundreds of feet or meters from the mechanical room within the building.

Collection vaults are sometimes made of cast concrete, but the preferred designs of vaults are fabricated from HDPE materials, often using large diameter pipes and flat sheets welded together as a vertical column or tower, water-tight and safe for access by installers and maintenance crews. Horizontally oriented designs are used for systems with larger manifolds. See **Figure 12** as examples of horizontal vaults.

The underground collection vault typically contains one or more distribution manifolds, depending on the size of the system. The vault may be centrally located in the midst of several ground heat exchangers, with larger diameter supply and return pipes transferring the heat exchange fluid to the heat pumps in the mechanical space.

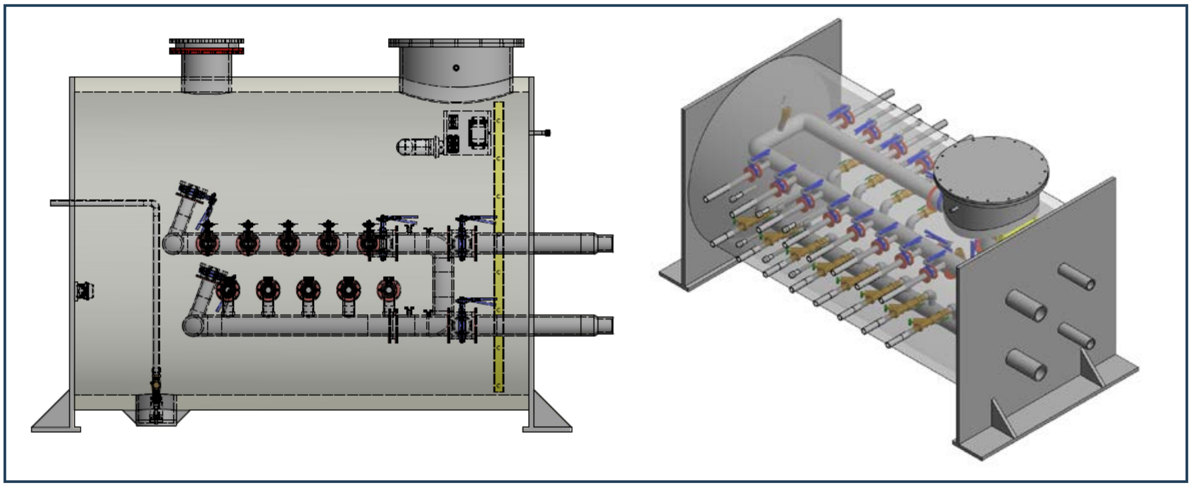

Figure 12a (left) & 12b (right): Examples of HDPE collection vaults with integrated manifolds (different designs)

7.0 HEAT TRANSFER FLUIDS

The type of heat transfer fluid or medium used in a ground source geothermal system can vary, depending on factors such as system design, required thermal performance (e.g., fluid specific heat), pumping performance (e.g., viscosity), local regulations, cost, availability, and contractor preference.

While some closed-loop geothermal systems may use only water as the fluid, when it is determined that any segment of the geothermal ground loop is subject to freezing, adequate antifreeze protection should be included, utilizing an approved heat transfer fluid type such as:

- Propylene glycol with approved corrosion inhibitors and environmental stabilizer additives to be mixed with water
- Ethanol with approved corrosion inhibitors and environmental stabilizer additives to be mixed with water
- Methanol with approved corrosion inhibitors and environmental stabilizer additives to be mixed with water
- Other heat transfer fluids in accordance with CSA/ANSI/IGSHPA C448 or local codes.

Designers must also ensure that the heat transfer fluid is compatible with components with which it comes into contact.

In general, the polyolefin-based plastic piping materials HDPE, PEX, PE-RT, and PP are resistant to the types of heat transfer fluids listed above, as proven through many years of field service. Test methods, such those found within the NSF/ANSI 358 series of product certification standards, are available to test and demonstrate the resistance of these piping materials to various fluids.

Some fluids may have characteristics that can be dangerous, such as flammability and toxicity to both the environment and humans, if not properly handled, mixed, and contained. Contact the heat transfer fluid manufacturer for a Safety Data Sheet (SDS) (formerly Material Safety Data Sheet or MSDS) and for specific information about environmental safety and hazards.

Industry standards, codes, and local regulations will often specify which types of heat transfer fluid/s are permitted or prohibited for use in the specific jurisdiction or location. Some jurisdictions require that heat transfer fluids are non-toxic and/or non-flammable. System designers and installers must check local regulations before specifying the heat transfer fluid.

Since the heat transfer capacity or “specific heat” varies from one fluid to the next, this selection of an approved fluid should be done before sizing the geoexchange loop field, since a change in the heat transfer fluid could alter the amount of ground loop piping that is required for the desired heat exchange capacity of the system.

8.0 STANDARDS, CODES, AND REGULATIONS

Several industry standards, codes, and regulations exist to guide industry professionals about the design and installation of closed-loop ground-source geothermal heating and cooling systems. These documents may be enforced as codes or referenced within codes and regulations for given jurisdictions. Designers, specifiers, and installers must verify which standards, codes, and regulations apply for the jurisdiction of each system.

A list of the most common standards and codes, and other referenced industry documents, and their sources, follows:

- CSA/ANSI/IGSHPA C448 *Design and installation of ground source heat pump systems for commercial and residential buildings* www.csagroup.org
- ANSI/AHRI/ASHRAE ISO Standard 13256-1 *Water-source heat pumps - Testing and rating for performance - Part 1: Water-to-air and brine-to-air heat pumps* www.ashrae.org
- ANSI/AHRI/ASHRAE ISO Standard 13256-2 *Water-source heat pumps - Testing and rating for performance - Part 2: Water-to-water and brine-to-water heat pumps*
- ASHRAE Handbook: HVAC Applications (Ch. 35 Geothermal Energy)
- ASHRAE 194 *Method of Test for Direct-Expansion Ground-Source Heat Pumps*
- ASTM D2683 *Standard Specification for Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing* www.astm.org
- ASTM D2737 *Standard Specification for Polyethylene (PE) Plastic Tubing*
- ASTM D2774 *Standard Practice for Underground Installation of Thermoplastic Pressure Piping*
- ASTM D2837 *Standard Test Method for Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials or Pressure Design Basis for Thermoplastic Pipe Products*

- ASTM D3035 *Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter*
- ASTM D3261 *Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing*
- ASTM D3350 *Standard Specification for Polyethylene Plastics Pipe and Fittings Materials*
- ASTM F714 *Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Outside Diameter*
- ASTM F876 *Standard Specification for Crosslinked Polyethylene (PEX) Tubing*
- ASTM F1055 *Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene and Crosslinked Polyethylene (PEX) Pipe and Tubing*
- ASTM F2389 *Standard Specification for Pressure-rated Polypropylene (PP) Piping Systems*
- ASTM F2623 *Standard Specification for Polyethylene of Raised Temperature (PE-RT) SDR 9 Tubing*
- ASTM F2769 *Standard Specification for Polyethylene of Raised Temperature (PE-RT) Plastic Hot and Cold-Water Tubing and Distribution Systems*
- AWWA C901 *Polyethylene (PE) Pressure Pipe and Tubing, 3/4 in. (19 mm) through 3 in. (51 mm) for Water Service*
- CSA B137.1 *Polyethylene Pipe, Tubing, and Fittings for Cold Water Pressure Services*
- CSA B137.5 *Crosslinked Polyethylene Tubing Systems for Pressure Applications*
- CSA B137.11 *Polypropylene (PP-R and PP-RCT) pipe and fittings for pressure applications*
- CSA B137.18 *Polyethylene of raised temperature resistance (PE-RT) tubing systems for pressure applications*
- IAPMO *Uniform Mechanical Code (UMC)* www.iapmo.org
- IAPMO *Uniform Solar, Hydronics and Geothermal Code* (USHGC)
- ICC *International Mechanical Code (IMC)* www.iccsafe.org
- ICC *International Residential Code (IRC)*
- ISO 9080 *Plastics piping and ducting systems - Determination of the long-term hydrostatic strength of thermoplastics materials in pipe form by extrapolation*
- NSF/ANSI 14 *Plastic Piping System Components and Related Materials*
- NSF/ANSI/CAN 61 *Drinking Water System Components – Health Effects*
- NSF/ANSI 358-1 *Polyethylene (HDPE) Pipe and Fittings for Water-Based Ground-Source "Geothermal" Heat Pump Systems* www.nsf.org
- NSF/ANSI 358-2 *Polypropylene Pipe and Fittings for Water-Based Ground-Source "Geothermal" Heat Pump Systems*
- NSF/ANSI 358-3 *Crosslinked Polyethylene (PEX) Pipe and Fittings for Water-Based Ground-Source "Geothermal" Heat Pump Systems*
- NSF/ANSI 358-4 *Polyethylene of Raised Temperature (PE-RT) Pipe and Fittings for Water-Based Ground-Source "Geothermal" Heat Pump Systems*

- PPI TN-17 *Crosslinked Polyethylene Pipe & Tubing* www.plasticpipe.org
- PPI TR-3 *Policies and Procedures for Developing Hydrostatic Design Basis (HDB), Hydrostatic Design Stresses (HDS), Pressure Design Basis (PDB), Strength Design Basis (SDB), Minimum Required Strength (MRS) Ratings, and Categorized Required Strength (CRS) for Thermoplastic Piping Materials or Pipe*
- PPI TR-4 *PPI Listing of Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe*
- PPI TR-48 *R-Value and Thermal Conductivity of PEX and PE-RT*
- PPI MS-7 *Model Specification for Plastic Piping Materials for Ground Source Geothermal Applications*

Keywords: Borehole, closed-loop, coaxial piping, concentric, directional drilling, earth energy, energy piles, GHP, GSHP, geoexchange, geothermal, ground heat exchanger, ground source, HDD, inclined drilling, lake loop, open-loop, pond loop, surface water exchange, U-bend assembly, HDPE, PEX, PE-RT, PP-R, PP-RCT