PPI Handbook of Polyethylene Pipe

HVAC Applications

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HVAC APPLICATIONS

FOREWORD

HVAC Applications is one of the chapters in the Plastics Pipe Institute's *PPI Handbook of Polyethylene Piping*. Other topics to be addressed in the handbook will include design of polyethylene piping systems, joining procedures, engineering properties, directional drilling and a variety of related information.

The *PPI Handbook of Polyethylene Piping* is being produced by the Municipal and Industrial (M&I) Division of PPI. M&I membership consists of major North American manufacturers of polyethylene (PE) pipe and fittings, PE piping materials, machinery, and equipment used for joining and installing PE piping, related test laboratories, and professional organizations.

PPI addresses other applications, such as gas distribution. PPI and its subgroups provide technical and promotional support for the effective use and continued application of thermoplastics pipe and related products, consistent with the best public interest. PPI membership also includes producers of polyvinyl chloride (PVC), chlorinated polyvinyl chloride (CPVC), and cross-linked PE (PEX) piping products and materials.

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INTRODUCTION

The performance and use characteristics of polyethylene pipe make it an ideal choice for use in certain HVAC – Heating, Ventilation, and Air Conditioning – applications. Typically, HVAC is thought of as flexible vent pipes, steam pipes, etc… However, since the 1980's polyethylene pipe's flexibility, strength, and ease of use has had a major impact on HVAC applications such as geothermal heat pumps, and radiant heating.

This chapter presents information and design criteria for the use of polyethylene pipe in applications such as:

> **Ground Source Heat Pumps** - basic use and standards, configuration, joining methods, and installation considerations.
>
> **Radiant Heating Systems** - HDPE and PEX (crosslinked PE), operating temperatures, oxygen barriers, and installation considerations.
>
> **Solar Applications** – use of PE pipe for solar water heating applications.
>
> **Vacuum Systems** – use and design limitations.

GROUND SOURCE HEAT PUMP SYSTEMS

Due to polyethylene pipe's versatility, flexibility, durability, leak proof fusion joints, and ease of use, it has become a key component in the success of Ground Source Heat Pumps.

There are two basic types of heat pumps – air source and ground source. An air source system utilizes temperature variations with the air to gain operating efficiency. A Ground Source, or Geothermal, Heat Pump System uses an electric pump to circulate fluid from the heat pump cycle, through a series of polyethylene pipes buried in the ground to take advantage of the relatively constant ground temperatures. These pipes are known as Ground Heat Exchangers. In simple terms, in the summer the heat pump's refrigerant cycle transfers heat from the building, into the circulating fluid. The fluid is then circulated through the ground heat exchanger where the ground acts as a heat sink, cooling the fluid before it returns to the building. In the winter, the system works in reverse. The heat pump uses the earth to warm the circulating fluid, which is then transferred back to the inside heat exchanger. In addition to heating and cooling the air, a desuperheater can be added to this cycle that can provide most, if not all, hot water for use in the building as well.

The properties that control this process are based on the ability of the PE pipe to transfer heat either out of, or into, the system. The heat transfer by conduction mechanism that governs this system is the same as any heat exchanger. It is assumed that the ground is at a steady state condition. This type of heat transfer mechanism is governed by the basic equation:

[illegible]

where:

Q = Heat transfer, BTU/hr
k = Thermal transfer coefficient, BTU/hr*ft^2*°F
A= Surface area, ft^2
ΔT= Temperature differential, °F

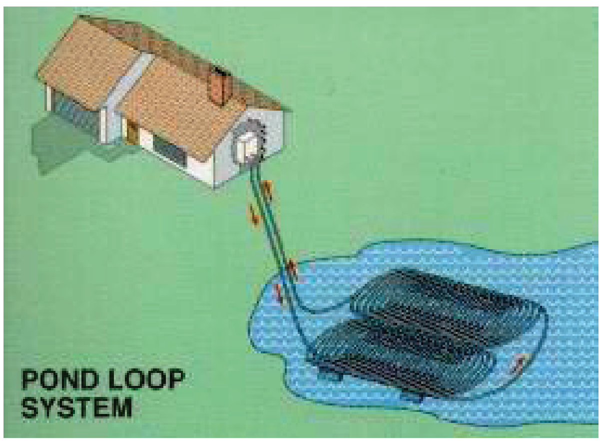
Polyethylene itself is typically considered an insulator and holds heat rather well. However, in this application, the benefits of the polyethylene pipe far out weight this performance characteristic. There are many other variables that need consideration when designing a GHP system. Most manufacturers have software available to aid in the determination of the size of the unit and the footage of pipe needed for the geothermal heat exchanger.

Geothermal heat pumps are very economical to operate and can save a substantial amount of money in operating costs over the life of the system. It has been reported[1] that a traditional furnace uses one unit of energy and returns less than one unit back as heat. A ground source heat pump uses one unit of energy and returns as much as three units back as heat. The polyethylene pipe acting as the heat transfer medium with the ground helps make this possible.

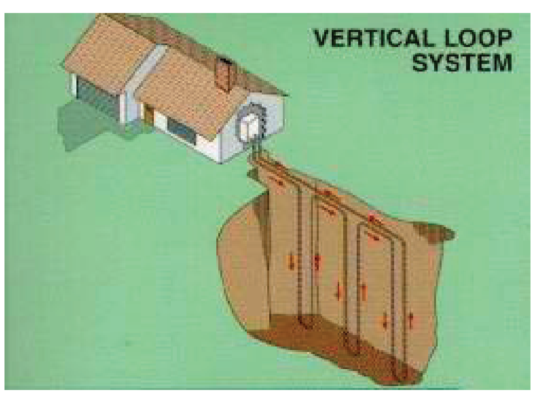
Types of Ground Heat Exchangers

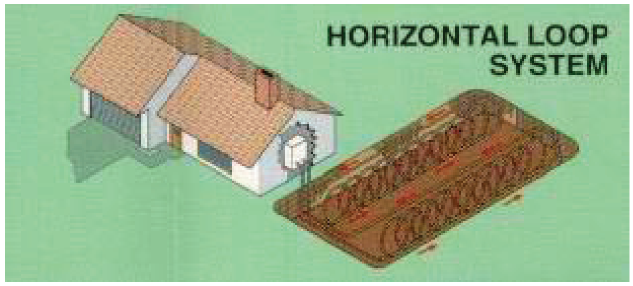
The polyethylene pipe used in the ground heat exchanger can be configured several different ways depending on the size of the system, surrounding land, or availability of a large open water source. The two basic types are open systems and closed systems.

Open systems require a suitable supply of water where open discharge is possible. This type of system uses the HDPE pipe to bring fresh water to the heat pump, and then discharges the water back into the water supply. Only fresh water is used and there is no need for a special heat transfer, or antifreeze solution. Some key PE pipe design considerations for an open system is are the fact that the system will have a suction and discharge loop. This means the pipe may need to handle negative vacuum pressures and positive pumping pressures.



The more common type of GHP installation is a closed loop system. A closed system is just that, a “closed loop” recirculating system where the HDPE pipe circulates an “antifreeze” solution continuously. This type of system can be installed several different ways such as: a pond loop system, a vertical loop system, or a horizontal (slinky) loop system. Each of these types of installations utilizes the basic performance benefits and versatility of HDPE pipe to get the most beneficial type installation for the surrounding conditions.





Pipe Specifications and Requirements

Polyethylene pipe is the material of choice for the ground heat exchanger in a ground source heat pump system. The International Ground Source Heat Pump Association (IGSHPA) has developed some design and installation standards for the HDPE pipe that is required for a geothermal heat exchanger. Specifications for polyethylene pipe and fittings used in the geothermal heat exchanger are as follows:

1. General – All pipe and heat-fused materials shall be manufactured from virgin polyethylene extrusion compound material in accordance with ASTM D 3350. Pipe shall be manufactured to outside diameters, wall thickness, and respective tolerances as specified in ASTM D 3035, or D 2447. Fittings shall be manufactured to diameters, wall thickness, and respective tolerances as specified in ASTM D 2683 for socket fittings, ASTM D 3261 for butt fittings and ASTM F 1055 for electrofusion fittings.

2. Material – The material shall maintain a 1600 psi hydrostatic design basis at 73.4°F (23°C) per ASTM D 2837, and shall be listed in PPI's TR-4 as a PE 3408 compound. The material shall be a high density extrusion compound having a minimum cell classification of 345434 with a UV stability of C, D, or E as specified in ASTM D 3350 with the following exception: this material shall exhibit zero failures (F_0) when tested for a minimum of 192 hours under ASTM D 1693, condition C, as required in ASTM D 3350.

3. Dimensions – Pipe with a nominal diameter of less than 1 _" shall be manufactured in accordance with ASTM D 3035 with a maximum SDR of 11.

Pipe manufactured with a nominal diameter of 1 _" and larger shall be made in accordance with ASTM D 3035 with a maximum DR of 15.5, or ASTM D 2447 schedule 40. If the pipe is used in a vertical bore application it shall be manufactured in accordance with ASTM D 3035 with a maximum DR of 11.

Pipe 3" nominal diameter and larger shall be manufactured in accordance with ASTM D 3035, with a maximum DR of 17, or D 2447 schedule 40.

4. Markings – Sufficient information shall be permanently marked on the length of pipe as defined by the appropriate ASTM pipe standard.

5. Certification materials – Manufacturer shall supply a notarized document confirming compliance with the above standards.

This specification is from the IGSHPA "*Closed Loop/Geothermal Heat Pump Design and Installation Standards 2000*". For the most current revision contact IGSHPA at Oklahoma State University.

Table 1
Maximum Allowable Operating Pressures (MAOP) at 73.4°F and 140°F for Specified DR's in Ground Heat Exchangers

Pipe	MAOP (psig)		
DR	73.4°F (HDB=1600 psi)	140°F (HDB=800 psi)	140°F (HDB=1000 psi)
9	200	100	125
11	160	80	100
15.5	110	55	69
17	100	50	63

Notes: 1) PE 3408 at 73.4°F HDB of 1600 psi
2) DF = 0.5
3) HDPE pipe is not rated for service above 140°F

The recommended specification takes into account the optimum performance based on the need to make sure the pipe and fittings can handle the pressures and stresses involved in the application, as well as the heat transfer requirements for the heat exchanger itself. Heavier wall pipe may be able to handle higher pressures and stresses, but the thicker wall lowers the heat transfer efficiency with the ground. All of these parameters must be balanced. When designing the PE pipe heat exchanger, maximum operating pressures and temperatures, as well as head and surge pressures must be taken into account.

For closed-loop geothermal heat exchangers, even though a high stress crack resistant polyethylene is required, it is appropriate to make sure the antifreeze solution used in the heat exchanger does not adversely affect the stress crack performance of the pipe and fittings. The antifreeze solution manufacturer should be able to supply this information.

More information on the design of PE pipe systems for pressure, surges, flow capacities, and etc can be found in the design chapter of this handbook.

Pipe Joining Methods

Polyethylene pipe can be joined by several different methods. One of the best attributes of PE pipe is its ability to be heat fused producing a 100% leak proof joint that is as strong, or stronger, than the pipe itself. Extensive information on joining PE pipe can be found in the joining chapter of this handbook.

IGSHPA recommends acceptable methods for joining as 1) a heat fusion process, or 2) stab-type mechanical fittings to provide a leak-free union between the pipe ends that is stronger than the pipe itself. This type of mechanical joint is also known as a Category 1 mechanical joint according to ASTM D 2513.

In addition, it is recommended that fusion transition fittings with threads must be used to adapt to copper pipe or fittings. Fusion transition fittings with threads or barbs must be used to adapt to high strength hose. Barbed fittings are not permitted to be connected directly to the polyethylene pipe, with the exception of stab-type fittings as described above. All mechanical connections must be accessible.

Since mechanical connections must be accessible, fusion joints are typically used wherever possible. Butt, socket or electro-fusion is used to join individual sections of pipe. “U-bend” fusion fittings are used for creating the return line in vertical bores. In fact, it is common for polyethylene pipe made for geothermal heat exchangers to be double wrapped on a coil and the “u-bend” fitting fused on at the factory. This makes insertion into a vertical bore very quick and easy. Sidewall fusion can be used to join parallel pipe loops to a header. All fittings must be pressure rated for the expected operating and surge pressures, and joined according to the manufacturer’s recommended procedures. This is a critical feature since this joint will be at the bottom of a well and grouted into place. Repairing a leaking joint would be very difficult. However, due to polyethylene pipe’s ability to create very strong fusion joints, this concern is easily overcome.

Pipe Installation

As discussed previously, there are several types of installation choices for ground source heat pumps. It is important to follow the GHP manufacturer’s requirements for the type of unit being used. This will define the amount of pipe needed for the particular installation and environment. However, there are some general guidelines for polyethylene pipe that will help assure a successful installation.

Generally, it is desired to keep the diameter of the HDPE pipe as small as possible, but not so small that pumping power to circulate the antifreeze solution becomes too great, thus losing the operating efficiency of the GHP. The smaller the diameter, the higher the surface to volume ratio will be, and the better chance for turbulent flow inside the pipe. Both of these conditions promote more efficient heat transfer. Most ground heat exchangers are constructed from _” to 2” pipe. The headers will be 1 _” to 2”, and the individual loops will be _”, 1” or 1-1/4”. The amount of pipe utilized varies depending on environmental conditions and how much heating or cooling capacity is needed. As an example, a typical 3-ton ground heat exchanger may use 200 feet of headers and 400 feet for each parallel loop.

If trenching for a horizontal installation or header system, avoid sharp bends around corners. Pipe manufacturers have a minimum bend radius that will assure that the pipe is not over stressed. If a sharp corner is needed, utilize an elbow fitting. Remove any sharp rocks from backfill material. Long-term contact between the polyethylene pipe and a sharp object could lead to premature failure of the pipe. Even though the polyethylene pipe is very stress crack resistant, it is a good idea to minimize this type of contact. The addition of sand in the bottom of the trench will help minimize incidental contact with sharp objects. It is also possible to plow the pipe directly into the ground using a vibratory plow. This works well up to 3-4 feet depth in areas with loose or unstable soils, and where there are not an excessive amount of rocks that could impinge on the pipe over time.

Vertical bores for ground heat exchangers are typically much simpler than drilling a water well. Generally casing is not needed if the borehole is sufficiently stable long enough to get the pipe loop installed. It is sometimes more economical to have several shallow bores rather than one deep bore. However, the bores need to be more than 50 ft. to be assured of reaching depths where ground temperatures are cooler and constant. Vertical bores must be backfilled appropriately to be sure the pipe loops have intimate contact with the soil or grout. If there are air gaps around the pipe, the heat transfer by conduction will be negatively affected.

For both types of installations leave a significant portion (3-5% of total length) of pipe extending from the bores or trenches to compensate for any relaxation from stretching, or contraction from temperature changes. Final connections to the header can be made after the system comes to steady state, usually with 24 hours.

Pressure Testing Ground Heat Exchanger
After installation of pipe is completed, but prior to backfilling and/or grouting, it is necessary to flush, purge and pressure test the system. Flushing any dirt or foreign matter that entered the piping during construction is necessary in order to minimize excessive wear on pumps and seals. Purging of any air pockets will made sure that all loops are flowing as intended and heat transfer will be optimized. Flushing and purging can be done at the same time.

Before charging the system with antifreeze, it is necessary to pressure test the system with water (not air) to make sure all of the joints and connections were done correctly. IGSHPA recommends that the heat exchanger be isolated and tested to 150% of the pipe design pressure, or 300% of the system operating pressure, whichever is less, when measured from the lowest point in the loop being tested. No leaks shall occur within a 30-minute test period. At this time flow rates and pressure drops can be compared to calculated design values. A minimum flow velocity of 2 ft/min. must be maintained for a minimum of 15 minutes to remove all air from the heat exchanger.

Since the PE pipe can expand slightly during this high level of pressurization, a certain amount of make-up water may be required. This is normal and does not indicate a leak in the system. If the pressure does not stabilize, then this may be an indication of a leak. Follow pipe manufacturer's guidelines for pressure testing of system.

For additional information of Ground Source Heat Pump design and installation contact:

International Ground Source Heat Pump Association (IGSHPA), 499 Cordell South, Oklahoma State University, Stillwater, OK 74078-8018 Toll-free: 1-800-626-4747, Telephone: (405) 744-5175, Fax: (405) 744-5283, or www.igshpa.okstate.edu.

American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), 1791 Tullie Circle, N.E., Atlanta, GA 30329 USA Phone: (404) 636-8400 Fax: (404) 321-5478, or www.ashrae.org.

RADIANT HEATING

WHAT IS RADIANT HEATING?

Radiant heating is when a heated fluid, such as water, is passed through tubes or pipes, in or under floors, walls, etc… The heated surface then becomes a huge radiator that warms the room and all objects and people in it mostly through radiant energy transfer. This type of heating provides superior comfort and efficiency when compared to traditional forced air convection heating.

As these surfaces are heated, they begin to radiate energy that is absorbed by other objects in the room, which in turn radiates energy to other cooler objects in the room. Radiant energy always goes from warmer to cooler objects. This temperature difference is the driving force behind heat transfer.

Heat Profile with Radiant Floor Heating

Heat profile with Traditional Convection Heating

Most of us are more familiar with convection heating. Air is forced passed a heated object, then forced through the house or building where the heat is transferred to cooler objects as it comes into contact with them. The other type of heat transfer is conduction. This occurs when two solid objects are in contact with one another. Again, the temperature difference between the two objects is the driving force for the energy transfer. Once the two objects achieve a steady state, (i.e. equalize in temperature) the energy transfer stops.

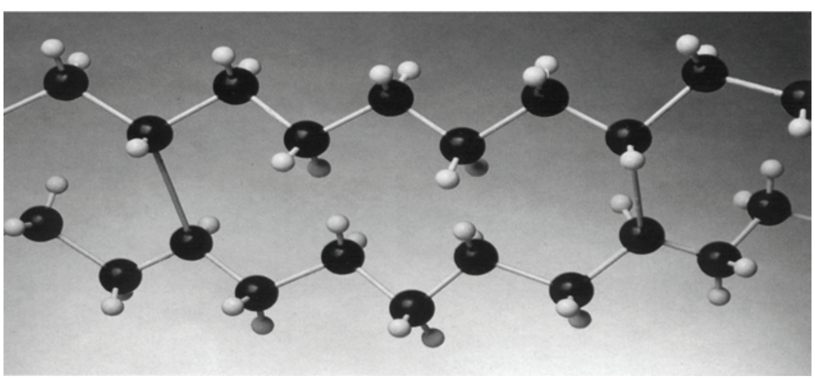
Radiant heating utilizes all three of these heat transfer modes in order to efficiently heat a house or building. The heating profile is much more uniform, meaning there are less cold and hot spots.

For outdoor applications radiant heating is used for snow melting of drives, courtyards, parking lots, etc… The same principles keep these surfaces warm enough so that snow and ice will not build up.

A certain type of polyethylene pipe has helped this form of heating to become very popular, as well as easier and more economical to install. Cross-linked polyethylene tubing is the material of choice for radiant heating installations. Crosslinked polyethylene, or PEX, has the strength, flexibility, and durability at these elevated temperatures to make these systems work.

Making PEX Tubing

The manufacture of PEX tubing can be very similar to making regular PE pipe and tubing. The polyethylene is extruded into a tubing shape and then the polyethylene chains, due to either a pre-extrusion or post-extrusion treatment, are cross-linked with one another. This process is fundamentally the same as vulcanizing rubber by using sulfur.



The post-extrusion treatment starts with extruding polyethylene tubing using conventional equipment. This tubing is then exposed to low-level radiation, which energizes the molecules and causes them to link to adjacent molecules. Gamma radiation was the original method, but now electron beam radiation is predominate. One advantage to this method is that the tubing can be reground and used again if not make correctly to dimensional specifications. Some drawbacks are expensive equipment and poor uniformity for degree of crosslinking on thicker parts.

The pre-extrusion treatment consists of mixing, or grafting, a cross-linking agent such as peroxide or a silane to the polyethylene chain. During extrusion this agent is activated by the high temperature and moisture, creating free radicals which then "link" to other nearby polyethylene chains. This reaction is initiated during extrusion, but depending on the particular cross-linking agent and curing conditions, can continue for hours until the free radicals sites are exhausted. Some advantages to this method are the degree if crosslinking is easier to control, it is more uniform, and no additional expensive equipment needed.

After the PE molecules are cross-linked, some of the physical properties of the PE change and it can now handle higher operating temperatures. This new ability is what makes PEX ideal for radiant heating applications.

The Plastics Pipe Institute TR-4 "*Hydrostatic Design Basis (HDB), Strength Design Basis (SDB), Pressure Design Basis (PDB) and Minimum Required Strength (MRS) Ratings for Thermoplastic Piping Materials or Pipe*", lists PEX materials for various operating temperatures and maximum stresses. Some PEX materials can be used continuously at maximum operating temperatures as high as 200°F, much higher temperatures than a normal PE 3408 type material.

Standards for PEX Tubing Systems
Most PEX tubing is made according to ASTM Standards:

F 876 *"Standard Specification for Crosslinked Polyethylene (PEX) Tubing"*, and

F 877 *"Standard Specification for Crosslinked Polyethylene (PEX) Plastic Hot-and Cold-Water Distribution Systems".*

Both standards cover only outside diameter controlled CTS sized tubing 1/8" to 2" diameter - SDR 9, and operating temperatures up to 180°F.

This tubing can be made with or without an EVOH (ethylene vinyl alcohol) oxygen barrier as an intermediate or outer layer. This barrier is sometimes required to minimize the oxygen transfer into a closed loop heating system, thus reducing the corrosion in boilers and other accessory items.

Fittings and Joining

Regular polyethylene pipe and tubing can readily be joined by heat fusion. This type of joining is one of the major benefits of PE pipe. However, due to the crosslinking PEX tubing for these types of applications is generally not joined in this manner. As a result, a range of mechanical couplings has been developed for most any joining need. Also due to the crosslinking effects, PEX can be joined by mechanical couplings that are not typically used on non-crosslinked PE pipe because of creep, cold flow, and stress crack concerns. There are several types of mechanical coupling systems available for PEX tubing - compression, flare, crimp ring, etc… Some ASTM Standards covering these fittings are listed in Table 2. It is recommended that no fittings be used for a continuous loop between the supply manifold to the return manifold.

Table 2
ASTM Standards for PEX Fittings

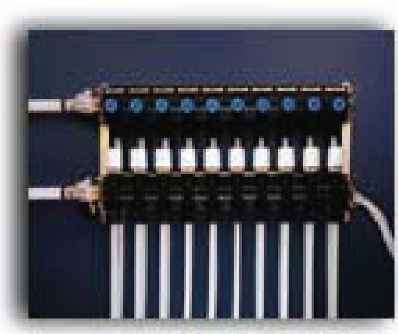
F 1807	Metal Insert Fittings Utilizing a Copper Crimp Ring for SDR 9 Cross-linked Polyethylene (PEX) Tubing.
F 1865	Mechanical Cold Expansion Insert Fitting With Compression Sleeve for Cross-linked Polyethylene (PEX) Tubing.
F 1960	Mechanical Cold Expansion Insert Fittings with PEX Reinforcing Rings for Use with Cross-linked (PEX) Tubing.
F 1961	Metal Mechanical Cold Flare Compression Fittings with Disc Spring for Cross-linked Polyethylene (PEX) Tubing.
F 2080	Cold Expansion Fittings with Metal Compression Sleeves for Cross-linked Polyethylene (PEX) Pipe.
F 2098	Stainless Steel Clamps for Securing SDR 9 Cross-linked Polyethylene (PEX) Tubing to Metal Insert Fittings.
F 2159	Plastic Insert Fittings Utilizing a Copper Crimp Ring for SDR 9 Cross-linked Polyethylene (PEX) Tubing.

It should be noted that in recent years heat fusion joining techniques have been developed for some PEX tubing and piping. Check with the manufacturer for recommended joining practices.

Installation of Radiant Piping

PEX tubing for radiant heating installations can be installed in new construction, or retrofitted within existing structures. In the floor is the most typical installation method, but tubing can be installed in walls and ceilings as well. The design of the system depends greatly on the structure and amount of heating required. This takes a trained and certified installer to make sure the system performs at optimum levels and that projected cost savings are realized. The hot water source for radiant heating is separate boiler designed specifically for this application. On rare occasions a residential hot water system can be used if the area to be heated is small.

Most installation use _" diameter tubing for residential applications and _" for commercial and snow melt systems. Supply and return lines are usually _" to 1" diameter tubing. The water to various zones is supplied from a main line into a manifold system that controls the individual zones. This way more or less heat can be directed to certain areas.



Manifold for Heating

The PEX tubing is laid out in continuous loops at a spacing determined by the designer. The incoming water is the warmest and is directed to the higher heat loss areas first. As the water circulates through the zone, it will cool, so the last section of tubing before exiting will be in the lower heat loss areas. The linear feet of tubing needed depends on many factors. But as a general rule-of-thumb a residential system will use 1-2 feet of tubing per square foot of floor space for normal heating requirements. For high heat loss areas the amount of tubing could increase to 2-4 linear feet of tubing per square foot of floor space.

The PEX tubing can be installed in flooring several different ways. For new construction, the tubing can be secured to the reinforcing wire mesh or steel rebar. This is done every 3-4 feet, or as needed, using plastic or soft metal ties, and the concrete or grout is poured over it. For suspended flooring, the tubing is attached directly to the wooden sub-flooring by using plastic clamps or special staples designed for this purpose. The tubing can also be installed to the underside of suspended flooring if needed.

PEX Tubing Layout on Floor for Radiant Heating

After laying and securing the loops the system should be tested to 100 psi to make sure the tubing has not been damaged during installation and to assure that the connection to the manifolds has been performed properly. Contact the tubing manufacturer for specific pressure testing protocols.

More information about radiant heating can be gotten from producer members of the Plastics Pipe Institute's High Temperature Division.

SOLAR APPLICATIONS

The use of solar energy was virtually nonexistent 25 years ago, but has grown to become a significant industry in the United States. Most solar applications are geographically concentrated in the states with a high percentage of sunshine - California, Arizona, New Mexico, Colorado, and Florida.

Solar heating systems range in size. The very simplest consist of nothing more than a black pipe lying in the sun connected to a swimming pool circulating pump. The more complex systems utilize collectors with 1, 2, or 3 layers of glazing plus piping and pumps. In addition, the later systems may include heat transfer fluids, heat storage tanks, heat exchangers, and temperature and pressure controls. PE piping can play a major role in this application. Its combination of flexibility, high temperature properties, resistance to freeze damage and corrosion are major advantages to this end-use. There are, however, precautions that should be taken to prevent misuse.

Not all polyethylene pipe is recommended for solar heating applications. Check with the manufacturer before use.

Features and Benefits
The performance benefits of polyethylene pipe in solar heating are;

Ease of Installation - Minimizing the overall cost of solar heating is important to make them viable alternatives and to expand customer acceptance. Polyethylene pipe and tubing is available in many sizes and lengths. It's versatility and flexibility allows installations to be made with the most cost effective design.

Freeze Tolerant - Frozen lines can be a major problem. Although collectors are protected, supply lines need to be protected from freezing or they should be made of materials that are resistant to damage if water freezes. Polyethylene pipe can normal handle a full freeze situation without cracking or splitting.

High Temperature Resistance - For continuous use, polyethylene pipe must be suitable for high temperature environments. Polyethylene materials for use at elevated temperatures are listed in PPI's TR-4. Currently, the maximum rated temperature for polyethylene is 140°F (60°C). Some PEX materials can be used to 200°F (182°C). For use at higher temperatures contact the manufacturer for recommendations.

Collector Technologies
The most significant use of solar heating has been for swimming pool, domestic hot water, and space heating. Solar collectors are classified according to their water discharge temperatures: low temperature, medium temperature, and high temperature. Low temperature systems generally operate at a temperature of 110ºF and have a maximum stagnation temperature of 180ºF. Medium temperature collectors typically have discharge temperatures of 180-200ºF, but can generate stagnation temperatures of 280ºF, or more, for several hours. High temperature collectors routinely operate at temperatures of at least 210ºF and can generate stagnation temperatures of more than 400ºF. Pipe or tube made

of polyethylene can be used directly with low temperature collectors with no special precautions. In addition, PE piping is being used extensively inside unglazed collectors where temperatures rarely exceed 110ºF on a frequent basis.

To protect against ultraviolet exposure damage and to increase efficiency, plastic piping for use in collector panels should contain a minimum of 2% carbon black of proper particle size and with good dispersion. The carbon black has a two-fold benefit. One, the right kind of carbon black in the proper levels and adequately dispersed protects the PE from UV degradation for up to 40 years. Two, the carbon black aids in the absorption and retention of solar radiation, making the pipe more efficient in the collection of solar energy. Check with the pipe manufacturer for recommendations on long-term UV exposure resistance.

Plastic piping should not be used in conjunction with high temperature collectors such as the evacuated tube or concentrating types because of their extreme temperatures. In between these two extremes are the systems with medium temperature collectors that constitute the bulk of the market. These glazed collectors are used for domestic hot water and space heating systems. Depending on the type of collector and system design, some special precautions should be taken. The major types of medium temperature systems are described in the following paragraphs along with appropriate precautions. Medium temperature systems are either passive or active types.

Passive systems use no pumps or mechanical equipment to transport the heated water. The breadbox (passive) design uses a tank placed under a glazing material. The tank is painted flat black or coated with selective absorber to increase the solar energy absorption. The collector may be the primary storage tank or the storage tank may be in the house. In the later case, when a preset temperature is reached, water flows by gravity to the storage tank in the home and fresh water from the main is added to bring the system up to volume. In the thermosyphon passive design, a storage tank is mounted above a collector and cold water flows down into the collector. As the water is heated in the collector, it rises through thermosyphon action back up to the storage tank. Because of the large volume of water in the collector, passive solar systems are not subject to high stagnation temperatures. Thus, polyethylene piping can be used throughout, including a hook-up directly to the collector system.

Active solar systems utilize a pump to move heat transfer fluids through the collector. Some utilize potable water as the heat transfer fluid (open systems) while others use solutions such as ethylene glycol, propylene glycol, silicone oils, or hydrocarbon oils (closed systems). Hydrocarbon oil or silicone oils are generally not recommended with polyethylene pipe. In closed systems, heat is transferred from the heat transfer fluid to potable water by means of a heat exchanger in the hot water storage tank. There are many types of heat transfer fluids, and it is necessary to verify with the manufacturer of the pipe that the fluid being used is compatible and will not negatively affect the long-term performance of the pipe or other system components.

Precautions

The extreme conditions encountered during stagnation can be a problem in active, medium temperature collectors. As mentioned earlier, stagnation temperatures can exceed 280ºF in most active, medium temperature collectors. Under no circumstances should any PE piping be used inside the collector, or in the system where it will be exposed to such temperatures unless that material has been qualified for service at those elevated temperatures.

Installation

In general, solar collector manufacturers do not provide piping for the system.

The installer most likely will purchase the piping from the local plumbing supply wholesaler or solar supply house. Installers are usually plumbers, but in some areas like California, solar specialists also do installations. A qualified plumbing supply house may also perform installations. The installation requires knowledge of carpentry to provide roof support or mounting, electricity to install the control system, and plumbing to install the piping system and to tie it in to the storage tank and the existing domestic water supply. Always be sure the installation meets the requirements of the local building, plumbing and mechanical codes.

VACUUM SYSTEMS

Even though polyethylene pipe is normally used for internal pressure applications, it can also be used for vacuum systems as well. Some of the advantages of using PE pipe for vacuum lines are flexibility and heat fusion joining.

The increased flexibility means the pipe or tubing can more easily bend around curves removing the need for additional fittings. However, minimum bend radius restriction from the manufacturer should be followed. As a general rule-of-thumb, the minimum bend radius for PE pipe is 25 times the outside diameter (i.e. 25 OD's), and 100 OD's where there are fittings in line. The minimum bend radius may be more for thinner walled pipe.

Heat fusion joining gives a completely leak proof joint, whereas a mechanical fitting may leak under a vacuum situation. Fusion joining information can be found in the PPI's Engineering Handbook – *Joining*, or from the pipe manufacturer.

Critical Buckling Under Vacuum

A vacuum situation can be designed the same way as an unconstrained external hydrostatic loading application. A full vacuum is 14.7 psi (1 atm). A polyethylene piping system can be designed to handle whatever amount of vacuum required, but a vacuum can physically never be more that 14.7-psi. However, if other conditions such as groundwater are present, the total effective loading may be higher and should be taken into consideration.

To see if a PE pipe can handle this amount of loading the unconstrained buckling equation is used:

where:

	P_{uc}	= Unconstrained critical bucking pressure, psi
	E	= Elastic modulus (time dependent)
	μ	= Poisson's Ratio = 0.35 for short-term loading
	DR	= Dimension ratio
	f_o	= ovality compensation factor, 0.62 for 5% ovality
	N	= Safety factor, normally 2.0

The value of the elastic modulus for polyethylene is time dependent as shown in Table 3. Most vacuum situations will be short-term and the initial short-term elastic modulus can be used. If it is determined that the vacuum will be continuous for a long period of time, then a reduced effective modulus should be used. However, with polyethylene these reduced time dependent physical properties are for continuous times only – the times are not additive. If the vacuum is to be applied for 1 hour then released for a time, then reapplied, the times are not added together. The initial short-term modulus can be used in the calculations. For more information on the effects on the elastic modulus with time and stress see the engineering properties chapter of this handbook.

Table 3
PE Elastic Modulus as a Function of Time

Duration of Load	Apparent Modulus of Elasticity, E
Short-term	110,000 psi (800 MPa)
1 hour	90,000 psi (620 MPa)
10 hours	57,500 psi (400 MPa)
100 hours	51,200 psi (350 MPa)
50 years	28,200 psi (200 MPa)

Note: Values shown are for a typical PE 3408 material.

Let's assume that the vacuum is to be applied for periods of less than 1 hour. Therefore the short-term modulus can be used. Also, f_0 is approximately 0.62 for 5% ovality, and a typical engineering safety factor is 2. By plugging in these values and solving for DR, to handle a full, short-term vacuum without collapse, the SDR needed is 17. If severe bends or tensile stresses are being applied to the pipe at the time of vacuum, a heavier wall pipe may be needed. Table 4 shows level of vacuum other SDR's can handle under the same conditions.

Table 4
Short-Term Vacuum Levels for Various SDR's

SDR	Short-Term Vacuum (psi)
17 or less	14.7
21	9.7
26	5.0
32	2.6
41	1.2

Due to polyethylene's flexibility and elastic memory, if the piping is completely flattened by a vacuum, once the vacuum is released the piping can return to its original shape. This will depend on how long the pipe remained flattened.

CONCLUSION

From this discussion, it is apparent that polyethylene pipe or cross-linked polyethylene pipe (PEX) may be used in a broad array of applications. This chapter in particular has focused on some of the more innovative uses of these uniquely capable plastic piping products in the HVAC applications such as ground source heat pumps and radiant floor heating. The reader is encouraged to contact the High Temperature Division of the Plastics Pipe Institute for more information regarding the use of these products in these and other applications.

REFERENCES

1. *Ground Source Heat Pump*, Popular Science, Feb. 1996, p.73, Times Mirror Magazines, Inc.

2. *Do It Naturally! Brochure*, International Ground Source Heat Pump Association, Oklahoma State University.

3. *Closed-Loop/Geothermal Heat Pump Systems, Design and Installation Standards 2000*, ed. P. Albertson, International Ground Source Heat Pump Association, Oklahoma State University, 2000.

4. *Geothermal Heat Pumps, Introductory Guide*, Rural Electric Research (RER) Project 86-1A, Oklahoma State University Division of Engineering Technology, Stillwater, OK.

5. *Water and Pipes*, pub. By Wirsbo Bruks AB, Sweden

6. *ASTM Annual Book, Volume 8.04 Plastic Pipe and Building Products,* American Society for Testing and Materials, Philadelphia, PA.

7. *Hydronic Radiant Heating Application Guide*, Vanguard Piping Systems, McPherson, KS.

8. *Hydronic Design Manual*, Quest – A Zurn Company, Commerce, TX.

9. Plastics Pipe Institute, Various Technical Reports, Technical Notes, Model Specifications, Washington, DC

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