CHAPTER 10
PIPING

Kevin D. Rafferty, P.E.
Geo-Heat Center
Klamath Falls, Oregon 97601

10.1 INTRODUCTION

The source of geothermal fluid for a direct use application is often located some distance away from the user. This requires a transmission pipeline to transport the geothermal fluid. Even in the absence of transmission line requirements, it is frequently advisable to employ other than standard piping materials for in-building or aboveground piping. Geothermal fluid for direct use applications is usually transported in the liquid phase and has some of the same design considerations as water distribution systems. Several factors including pipe material, dissolved chemical components, size, installation method, head loss and pumping requirements, temperature, insulation, pipe expansion and service taps should be considered before final specification.

In several installations, long transmission pipelines appear to be economically feasible. Geothermal fluids are being transported up to 38 miles in Iceland (Karlsson, 1982). In the U.S., distances greater than 5 miles, are generally considered uneconomical; however, the distance is dependent on the size of the heat load and the load factor.

Piping materials for geothermal heating systems have been of numerous types with great variation in cost and durability. Some of the materials which can be used in geothermal applications include: asbestos cement (AC), ductile iron (DI), slip-joint steel (STL-S), welded steel (STL-W), gasketed polyvinyl chloride (PVC-G), solvent welded PVC (PVC-S), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), cross-linked polyethylene (PEX), mechanical joint fiberglass reinforced plastic (FRP-M), FRP epoxy adhesive joint-military (FRP-EM), FRP epoxy adhesive joint (FRP-E), FRP gasketed joint (FRP-S), and threaded joint FRP (FRP-T). The temperature and chemical quality of the geothermal fluids, in addition to cost, usually determines the type of pipeline material used. Figures 10.1 and 10.2 introduce the temperature limitations and relative costs of the materials covered in this chapter. Generally, the various pipe materials are more expensive the higher the temperature rating. Figure 10.2 includes 15% overhead and profit (O&P).

Installation costs are very much a function of the type of joining method employed and the piping material. The light weight of most nonmetallic piping makes handling labor significantly less than that of steel and ductile iron in sizes greater than 3 in.

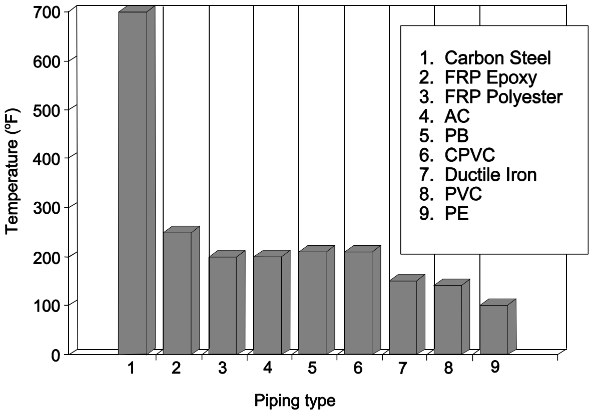

Figure 10.1 Maximum service temperature for pipe materials.

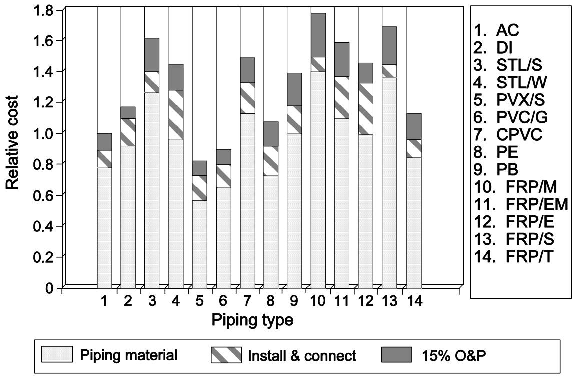

Figure 10.2 Relative cost of piping by type.

10.1.1 Piping Currently in Use

The following data was taken from a survey (Rafferty, 1989) of 13 operating geothermal district heating systems. The total main line (>2 in.) piping included in the systems reviewed for that report amounted to approximately 260,000 linear feet (lf).

Figure 10.5 provides a breakdown of the total piping by type in open systems, the most dominate design. As indicated, asbestos cement (AC) material is clearly the most widely applied product with approximately 55% of the total piping in these systems. Steel and fiberglass are a distant second to AC. Only minimum quantities of polybutylene, ductile iron and PVC are in use. Of note is the fact that there is increasing interest in ductile iron. Since publication of this data, ductile iron material has been almost universally selected for extensions of existing district heating systems. Its relatively low cost and simple installation techniques are similar to the now unavailable AC pipe. The PVC currently in use is all uninsulated piping in use on the collection network of one of the low temperature systems.

District heating systems can be designed as "open" or "closed" distribution networks. In the open design, the geothermal fluid is delivered directly to the customer. Waste or cooled fluid is collected in the return piping for delivery to the disposal facility. Closed systems, on the other hand, employ central heat exchangers to isolate most of the district system from the geothermal fluid. Heat is delivered to the customer via a "closed loop" of clean treated water.

The characteristics of open and closed systems are quite different. For example, closed systems generally employ insulated piping for both the supply and return piping; whereas, open systems may use insulation only on the supply piping. More importantly, open systems expose all of the piping to the geothermal fluids and as a result, corrosion considerations are more critical to these designs. Finally, the cost of closed systems is generally much higher than open systems. This is the result of costs associated with the central plant and the more extensive use of insulated piping.

Figure 10.3 provides a breakdown of total piping with respect to quantities used in open and closed distribution systems. As indicated, open systems constitute most of the piping applications.

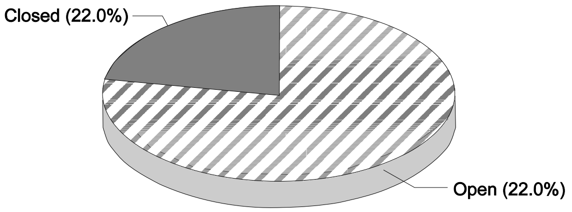

Figure 10.3 **Comparison of total amount of pipe used in open and closed geothermal district heating.**

For the piping used in the closed distribution systems, Figure 10.4 provides a breakdown by type. Clearly, steel piping is the choice for this application.

Figure 10.5 provides a similar breakdown for piping used in open systems. Again AC pipe has obviously been the material of choice for applications in which the pipe must be exposed to the geothermal fluid. Asbestos cement far exceeded its closest competitor (FRP approximately 18%) for this application. The previous popularity of AC, coupled with the fact that it is for practical purposes no longer available, underscores the need to identify a low cost alternative for this application.

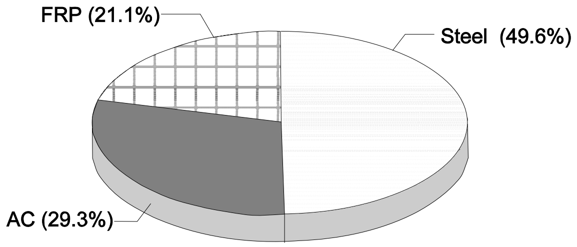

Figure 10.4 **Distribution of piping used in closed loop geothermal systems.**

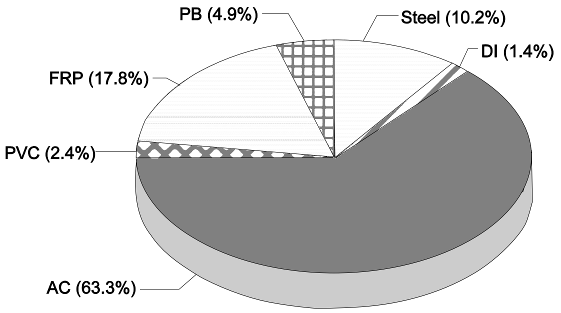

Figure 10.5 **Distribution of pipe used in open geothermal district heating systems.**

None of the geothermal district systems reviewed uses piping larger than 14 in. A breakdown of piping by size appears in Figure 10.6.

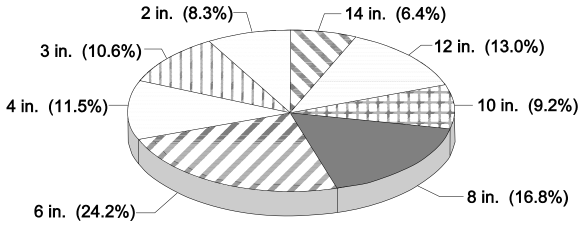

Figure 10.6 **Size distribution of piping in geothermal district heating systems.**

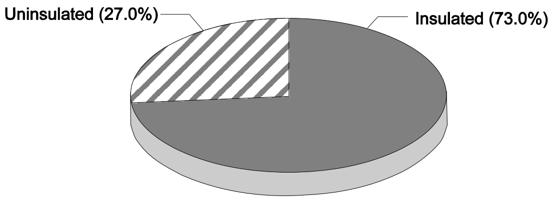

Figure 10.7 **Comparison of relative amounts of insulated and uninsulated pipe in geothermal district heating systems.**

As discussed above, many of these systems employ uninsulated piping on the return (or disposal) side of the distribution system. As indicated in Figure 10.7, fully 27% of all distribution piping in these systems is uninsulated. The prospect for increased use of uninsulated material in future systems is discussed later in this chapter.

10.2 PIPE MATERIALS

Both metallic and nonmetallic piping can be considered for geothermal applications. Carbon steel is the most widely used metallic pipe and has an acceptable service life if properly applied. Ductile iron has seen limited application.

The attractiveness of metallic piping is primarily related to its ability to handle high temperature fluids. In addition, its properties and installation requirements are familiar to most installation crews. The advantage of non-metallic materials is that they are virtually impervious to most chemicals found in geothermal fluids. However, the installation procedures, particularly for fiberglass and polyethylene are, in many cases, outside the experience of typical laborers and local code officials. This is particularly true in rural areas. The following sections review some specifics of each material and cover some problems encountered in existing geothermal systems.

10.2.1 Carbon Steel

Available in almost all areas, steel pipe is manufactured in sizes ranging from 1/4 to over 72 in. Steel is the material most familiar to pipe fitters and installation crews. The joining method for small sizes (<2-1/2 in.) is usually threading, with welding used for sizes above this level (Khashab, 1984). For underground installations, all joints are typically welded when unlined piping is used. For epoxy- lined piping, some form of mechanical joint should be employed so that welding does not interfere with the integrity of the lining material. Commonly used steel pipe ratings are Schedule 40 (standard) and Schedule 80 (extra strong). In most cases, in the U.S., Schedule 40 piping is used for heating applications, although, in Europe and for some newer non-geothermal district systems in the U.S., lighter weights (approximately Schedule 20) are now used. Schedule 80 is employed for high pressure applications or in cases where higher than normal corrosion rates are expected.

Corrosion is a major concern with steel piping, particularly in geothermal applications. As mentioned above, some allowance can be made by using the thicker-walled Schedule 80 piping. However, this approach is valid only for uniform corrosion rates. In many geothermal fluids, there are various concentrations of dissolved chemicals or gases that can result primarily in pitting or crevice corrosion. If the potential exists for this type of attack, or if the fluid has been exposed to the air before entering the system, carbon steel should be the material of last resort. See Chapter 8 for detailed information on corrosion and scaling concerns.

Steel piping is used primarily on the clean loop side of the isolation heat exchanger, although in a few cases it has been employed as the geothermal transmission line material.

A distinct disadvantage in using steel pipe is that the buried pipe is also subject to external corrosion unless protected with a suitable wrapping or cathodic protection. For example, the distribution system at Oregon Institute of Technology originally consisted of carbon steel pipe with a rigid foam cellular insulation wrapped with a mastic saturated with an asphalt material to provide a seal. The water seal degraded with time (approximately 15 years) and allowed groundwater to contact the pipe. External corrosion resulted in a number of failures and all of the steel pipe has been replaced with fiberglass piping located in a utility tunnel. The potential for external corrosion of metallic pipe systems should be considered for all direct buried installations. Various soil types, presence of ground-water, and induced current fields from power lines may accelerate external pipe corrosion and early system failure.

In at least two geothermal systems, unlined steel piping has performed well in normal operation but has suffered severe internal pitting corrosion during system shutdowns. In one case in which a system was down for approximately 6 months, carbon steel piping exhibited pitting corrosion rates of 70 to 200 mils/y (mpy) (Ellis and Conover, 1981). If unlined steel piping is employed on the geo-thermal side of the system, it is most critical to assure a complete internal drying of the material for extended shutdowns.

In both buried and aboveground installations, allowances for expansion must be made in the form of expansion joints or loops. These considerations have the effect of increasing both the labor and material costs of the piping system.

Galvanized steel has been employed with mixed success in geothermal applications. Some geothermal fluids have demonstrated the ability to leach zinc from solder and other alloys. Selective removal of the zinc from galvanized pipe could result in severe pitting corrosion. In addition, consideration should be given to the fact that the protective nature of the zinc coating is generally not effective above 135°F.

An indication of the costs for steel piping is shown in Table 10.1.

Table 10.l Steel Pipe Costs, Material Only (Means, 1996)

Size (in.)	Schedule 40 ($/lf)	Schedule 80 ($/lf)
2	3.46	4.73
4	10.16	14.12
6	17.71	34.76
8	43.39	65.56

Reference standards:

1. Pipe, American Society of Testing and Materials (ASTM A 53).

2. Fittings, American Standards Association (ASA) B16.9 (welded).

10.2.2 Ductile Iron

Ductile iron is similar to cast iron with the exception of the form of the carbon component. In cast iron, the carbon (graphite) is in a flake-like structure. In ductile iron, the structure is more spherical or nodular. This small difference results in the greater strength, flexibility, and machinability from which the product derives its name. Table 10.2 outlines physical properties of this material. Ductile iron has been described as more corrosion resistant than cast iron. However, the slight difference in corrosion resistance would not be of any substantive meaning in most geothermal applications. Cast iron piping was employed for over 80 years in the Warm Springs geothermal system (Boise, ID).

Table 10.2 Physical Properties of Ductile Iron Pipe

Property	Value
Coefficient of expansion	5.8×10^{-6} in./in.°F
Thermal conductivity	240 Btu in./h ft^2 °F
Specific gravity	7.12
Hazen - Williams flow factor	140

As an iron material, ductile iron is susceptible to corrosion from both external and internal sources. External protection generally involves a moisture barrier. For a pre-insulated product, special moisture protection would only be required at the joints and other fittings.

Internal corrosion protection is usually provided by a lining. The two most common materials are cement mor-tar and coal tar epoxy. Coal tar epoxy is limited to a temperature of approximately 120°F. Mortar lining, according to the Ductile Iron Pipe Producers Research Association, is suitable to a service temperature of 150°F with a protective seal coat. Without the seal coat, maximum service temperature is 212°F. In some applications with very soft water, a leaching of the mortar lining has been observed when a seal coat is omitted (Fisher, 1987). As a result, a special high temperature epoxy coating would be required. Unfortunately, quotes received by the San Bernardino Water District (operators of the San Bernardino, California, Geothermal District Heating System) for linings of this type for 130°F application would add $5.00 to $8.00/ lineal foot to the price of the pipe (Fisher, 1987). In applications where water chemistry is such that bare cement lining is accept-able, ductile iron could be an economical piping choice.

Ductile iron is a much-thicker-walled product than standard carbon steel and, for uniform corrosion applications, offers the probability of longer life. In geothermal applications, corrosion occurs by both uniform and pitting modes. Pitting corrosion rates of 70 to 200 mpy in carbon steel have been observed in one low-temperature (<150°F) system during shutdown periods.

Ductile iron pipe is the heaviest material of those covered in this chapter. As a result, it would incur additional handing costs in comparison to the lighter weight materials. Table 10.3 presents dimensional data for ductile iron piping.

Table 10.3 Ductile Iron Piping Dimensional Data

Size (in.)	Wall Thickness (in.)	OD Pipe (in.)	OD Bell (in.)	Weight (lb/lf)	Thickness Class	Pressure Rating (psi)
3	0.25	3.9	6.1	9.4	51	150
4	0.26	4.8	7.2	12.0	51	150
6	0.25	6.9	9.5	17.0	50	150
8	0.27	9.1	12.0	24.1	50	150
10	0.29	11.1	14.2	31.9	50	150

Ductile iron piping is cost competitive with asbestos cement material. In addition, its common use in water supply systems results in wider familiarity with its installation practices. Table 10.4 outlines costs for ductile iron piping.

The most common method of joining ductile iron piping is through the use of a push-on or Tyton type joint. This is a bell and spigot gasketed joint. In addition, several versions of mechanical joints are available, although these are characterized by higher cost than the push-on joints.

It is important to specify gasket materials suitable for the application temperature when using this product. Most suppliers offer EPDM gaskets which are suitable for use to 200°F.

Table 10.4 Costs For - Ductile Iron Piping (Uninsulated - Tyton Joint) (Means, 1996)

Size (in.)	Cost ($/lf)
4	8.35
6	9.45
8	12.50
10	16.95
12	21.00

Table 10.5 is a listing of ductile iron specifications and standards.

Table 10.5 Ductile Iron Specifications Standards

Standard	Description
ANSI/AWWA C150/A21.50	American National Standard for the Thickness Design of Ductile Iron Pipe.
ANSI/AWWA C151/A21.51	American National Standard for Ductile Iron Pipe, Centrifugally Cast in Metal Molds or Sand Lined Molds for Water and Other Liquids.
ANSI/AWWA C110/A21.10	American National Standard for Ductile Iron and Gray Iron Fittings 3 In. through 48 In. for Water and Other Liquids.
ANSI/AWWA C111/A21.11	American National Standard for Rubber Gasket Joints for Ductile Iron and Gray Iron Pressure Pipe and Fittings.
ANSI/AWWA C104/A21.4	American National Standard for Cement-Mortar Lining for Ductile Iron and Gray Iron Pipe and Fittings for Water.
ANSI/AWWA C105/A21.5	American National Standard for Polyethylene Encasement for Ductile Iron Piping for Water and Other Liquids.
ANSI/AWWA C600	American Water Works Association Standard for Installation of Ductile Iron Water Mains and their Appurtenances.

10.2.3 Fiberglass (RTRP)

Fiberglass piping, commonly referred to as RTRP (reinforced thermosetting resin pipe) or FRP (fiberglass reinforced plastic), is available in a wide vareity of configurations. Two materials are epoxy resin and polyester resin. In addition, the piping is available in lined and unlined versions. The epoxy resin piping with an epoxy liner is generally selected for geothermal applications. Both epoxy resin and polyester resin systems can be compounded to be serviceable to temperatures of 300ºF. Regardless of the type of fiberglass material used, care must be taken to maintain operating pressure high enough to prevent flashing of hot fluids. At high temperatures (>boiling point), the RTRP systems are susceptible to damage when fluid flashes to vapor. The forces associated with the flashing may spall the fibers at the interior of the pipe surface.

Fiberglass piping is available from a number of manufacturers but, at the distributor and dealer level, it is considerably less common than steel. Most manufacturers produce sizes 2 in. and larger. As a result, if fiberglass is to be employed, another material would have to be used for branch and small diameter piping of <2 in.

As with all nonmetallic piping, the method of joining is a large consideration with respect to both installation time and expense. With FRP piping, a variety of methods are available. Among the most popular are illustrated in Figure 10.8. Of these, the bell and spigot/adhesive has seen the widest application in geothermal systems.

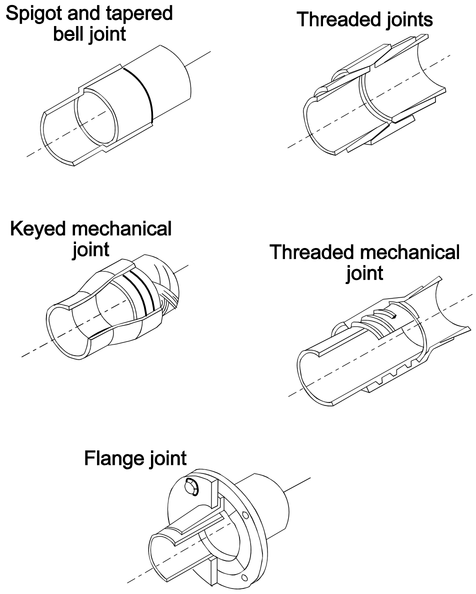

Figure 10.8 Joining methods for fiberglass piping.

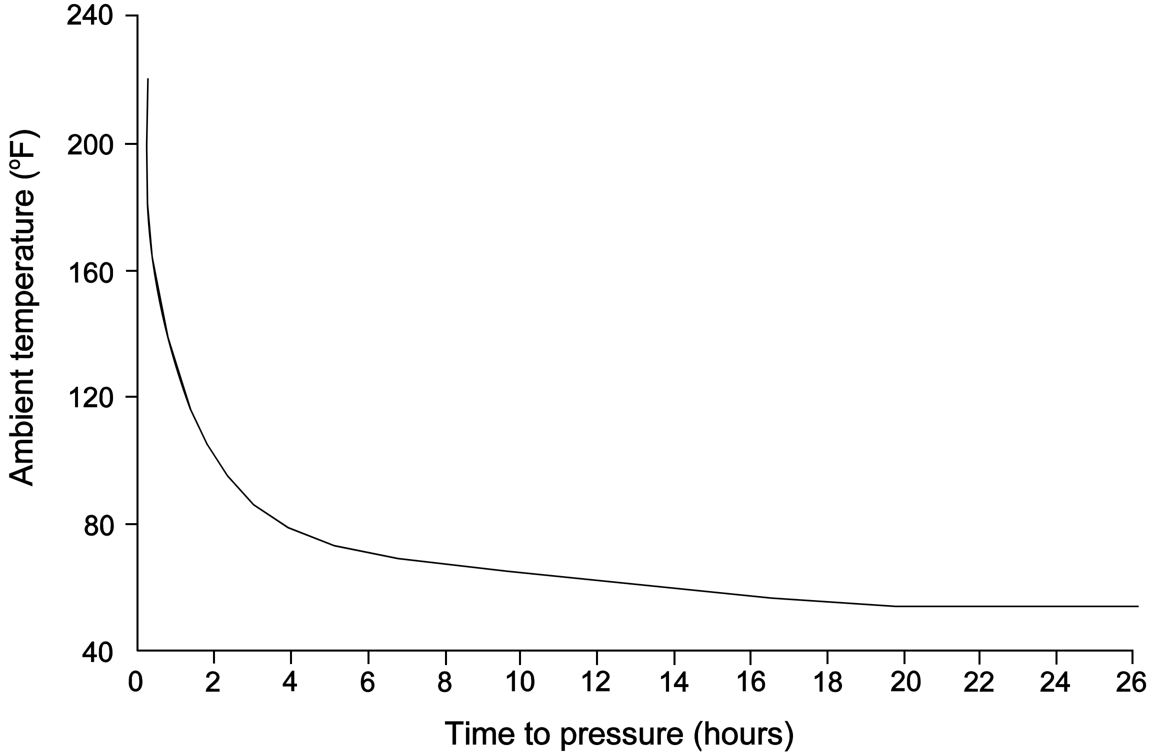

Figure 10.9 Setup time for epoxy adhesive.

In making the choice between the mechanical and adhesive type of joining, consideration should include piping cost, fitting cost, contractor familiarity, and probable installation temperature.

The cost of the keyed joint piping is approximately 10% more than the bell and spigot/adhesive joint in the 6 in. size. Alternate versions of mechanical joining are somewhat more expensive. The added cost of the keyed-type joint can be compensated for by the reduced labor necessary to complete the joint. Fitting cost should be carefully weighed with any mechanical joining system. If a large number of fittings are required, the labor savings can be quickly overshadowed by fitting material cost. In addition to the amount of labor required, the adhesive joint also demands a greater technical skill on the part of the installer. The epoxy adhesive must be properly mixed and applied to the joint under acceptable conditions to ensure a reliable set. One of the most important of these conditions is temperature. Figure 10.9 indicates the importance of ambient temperature on joint setup time.

Below approximately 75°F, curing time is substantially increased. As a result, if installation is to occur in a reasonable length of time, a special heating blanket must be applied to each joint after makeup to ensure proper curing. As with most other piping systems, the mechanical draw method is preferred for joint assembly.

Two recent developments which may be considerations are gasketed slip joint and integral thread joining. The slip joint approach provides for installation very similar to Tyton joint ductile iron or AC pressure pipe. Integral thread (with a double "O" ring) piping is also less labor intensive and low cost.

As shown in Table 10.6, the axial expansion of FRP is approximately twice that of steel. However, because of the relatively low axial modulus, forces developed as a result of this expansion are only 3 to 5% that of steel under the same conditions (Smith-Inland, 1982). As a result, for buried installations with at least 3 ft of cover, sufficient restraint is provided by the overlying soil and no special precautions need be made for expansion other than adequate thrust blocking. For aboveground installations (on hangers), changes in direction are the most economical method of allowing for expansion.

Table 10.6 Physical Properties of Fiberglass Pipe

Properties	Epoxy	Vinyl Ester
Coefficient of expansion	1.26 x 10^{-5} in./in. °F	1.05
Thermal conductivity	2.8 Btu in./h ft^2 °F	1.30
Specific gravity	1.8	1.85
Hazen-Williams flow factor	150	150

Fittings are available from most manufacturers in a wide variety of configurations. In general, the bell and spigot/ epoxy joint system offers a greater number of fittings than the keyed joint system. In fact, it is likely that some field made adhesive joints will be required even if a keyed joint system is selected. Fittings are available to convert from the fiber-glass connections system to standard flange connections. Saddle fittings of fiberglass construction are available for service connections. Standard piping lengths are 20, 30, and 40 ft.

Cost for fiberglass piping systems are shown in Table 10.7. It should be noted that fitting costs can constitute a substantial portion of the total cost for a piping system.

Table 10.7 Cost for Fiberglass Piping (epoxy lined/ adhesive type joint) (Means, 1996)

		Fittings		
Size (in.)	Pipe ($/lf)	Ell ($/ea)	Tee ($/ea)	Joint Kit ($/ea)
2	6.70	38	53	11
3	9.21	45	63	14
4	11.37	97	81	17
6	17.76	150	217	21
8	28.64	215	250	25
10	38.79	260	400	28
12	49.34	345	435	31

Standard ratings for FRP piping are shown in Table 10.8.

Table 10.8 Ratings for FRP Pipe

Size (in.)	OD (in.)	Wall Thickness (in.)	Weight (lb/ft)	Support Spacing (ft)	Pressure/Temp (psi/°F)
2	2.375	0.12	0.6	14.0	300/220 200/200
4	4.500	0.12	1.2	16.9	150/225 125/200
6	6.625	0.145	2.4	20.4	150/225 100/200
8	8.695	0.162	3.1	22.9	150/225 100/200
10	10.76	0.185	4.3	25.5	150/225 100/200
12	12.72	0.202	6.1	27.8	150/225 100/200

Appropriate standards and specifications for fiberglass pipe are shown in Table 10.9.

Table 10.9 Fiberglass Specifications and Standards

Standard	Descriptions
ASTM D 2310	Standard Classification for Machine Made RTRP.
ASTM D 2517	Standard Specification for Reinforced Epoxy Resin Gas Pressure Pipe and Fittings.
ASTM D 2996	Standard Specification for Filament Wound RTRP.
MIL-P-28584-4	Pipe and Pipe Fittings, Glass Fiber Reinforced Plastic for Condensate Return Lines.

10.2.4 Asbestos Cement (AC)

Asbestos cement pipe, sometimes referred to by the proprietary name of Transite, is a familiar material to most installation crews. It has been used for many years in municipal water systems. Recent concern about the carcinogenic nature of asbestos has resulted in an impact on the availability of AC pipe. Manufacturers have ceased production and it is unlikely the material will be available in the future.

The piping was manufactured in sizes of 3 to 24 in. and had a maximum service temperature of 200°F. For geothermal service, the piping was generally specified with an epoxy lining. In most cases, asbestos cement pressure pipe was the material employed. This piping was available generally in three pressure classifications: 100, 150, and 200, with Class 150 most frequently specified for geothermal service. Table 10.10 presents dimensional data for the material.

Table 10.10 Class 150 Asbestos Cement Pressure Pipe Information

Size (in.)	ID (in.)	OD (in.)	Weight (lb/lf)
4	4.00	4.77	6.1
6	6.00	7.05	11.1
8	8.00	9.22	16.5
10	10.00	11.43	22.7
12	12.00	13.69	32.1

Joining of the pipe at couplings and small branch take-offs can be accomplished with O-ring slip together joints made of the same material as the pipe (Johns-Mannville, 1982). The generally preferred method is that the pipe be attached to the coupling using the mechanical draw method. Fittings are available in cast iron or steel construction. In sizes applicable to geothermal systems, the cast iron material would be more commonly used. These fittings would be the same as those used in water main construction (AWWA 110). For both the fittings and the couplings, it is important to specify a gasket material that is compatible with the fluid being handled. This compatibility should consider both temperature and fluid chemistry. Most manufacturers can supply EPDM gaskets. Service connections to AC pipe can be accomplished for small diameter service lines with special tapped, AC couplings. In addition, standard mechanical service saddles can be used.

Table 10.11 presents basic physical properties of AC piping.

Table 10.11 Physical Properties of AC Piping

Property	Value
Coefficient of expansion	4.5×10^{-6} in./in. °F
Thermal conductivity	3.0 Btu in./°F ft^2 h
Specific gravity	2.03
Hazen-Williams flow factor	150

Expansion of AC is about the same as that of steel. Because of the construction of the AC couplings, all expansion is compensated for at the joint. As a result, expansion loops or joints are not required. Careful bedding proce-dures should be employed because of the relatively fragile nature of the pipe material.

Experience with 240°F geothermal water at the Raft River, Idaho project demonstrated that AC pipe is susceptible to thermal shock (Austin,1980). At lower system temperatures, the thermal shock is reduced and the AC pipe is not affected. In many installations, a system can be brought up to temperature and not subjected to the wide fluctuations and temperature cycling observed at Raft River. The AC pipe is performing satisfactorily in several low temperature (170°F) installations in California and Idaho including the San Bernardino, Susanville, and Boise district heating systems.

Cost for asbestos cement piping is shown in Table 10.12.

Table 10.12 Costs for AC Pressure Pipe Class 150 Including Coupling (Means, 1989)

Size (in.)	Cost $/lf
4	3.47
6	5.10
8	6.90
10	10.25
12	14.10

Appropriate standards of specification for AC piping are shown in Table 10.13.

Table 10.13 Specifications and Standards for AC Piping

Standard	Description
ASTM D1869	Rubber Rings for AC Pressure Pipe
AWWA C400	AWWA Standard for AC Pressure Pipe for Water and Other Liquids
AWWA C603	Standard for Installation of AC Water Pipe

10.2.5 Polyvinyl Chloride (PVC) and Chlorinated Polyvinyl Chloride (CPVC)

PVC is a low-temperature (maximum service temperature is 140°F) rigid thermoplastic material. It is manufactured in 0.5 to over 12 in. in diameter and is, next to steel, the most commonly available piping material. Common ratings used for plumbing applications are Schedule 40 and Schedule 80. In most applications, the Schedule 40 would suffice. For higher temperature suspended applications, the Schedule 80 material would require slightly less support. The most common method of joining PVC is by solvent welding. Schedule 80 material can also be threaded. Most types of fittings and some valves are available in PVC up to approximately 12 in. (Celanese, 1976). Table 10.14 presents a summary of PVC and CPVC physical properties.

CPVC is a higher temperature rated material with a maximum temperature rating of 210°F. Pressure handling ability at this temperature is very low (as is PVC at its maximum temperature) and support requirements are almost continuous. Table 10.15 outlines the effect of service temperature or pressure rating of PVC and CPVC piping materials.

Table 10.14 Physical Properties of PVC and CPVC

Properties	PVC	CPVC
Coefficient of expansion	3 x 10^{-5} in./in. °F	3.8 x 10^{-5} in./in. °F
Thermal conductivity	1.2 Btu in./h ft^2 °F	0.95 Btu in./h ft^2 °F
Specific gravity	1.39	1.55
Hazen-Williams flow factor	150	150

Table 10.15 Pressure Ratings for PVC and CPVC Pipe

Temperature (°F)	Pressure Rating PVC	CPVC
75	1.00	1.00
80	0.90	1.00
90	0.75	0.92
100	0.62	0.85
120	0.40	0.65
130	0.30	0.57
140	0.22	0.50
160	--	0.40
170	--	0.32
180	--	0.25
200	--	0.20

Table 10.16 presents weight and support requirements for PVC and CPVC.

Table 10.16 Weight and Support Requirements for Schedule 80

	Weight		Support Spacing			
			PVC		CPVC	
Size (in.)	PVC (lb/lf)	CPVC (lb/lf)	60°F (ft)	140°F (ft)	60°F (ft)	180°F (ft)
2	0.93	1.01	7	5	8	4
3	1.86	2.03	8	6	9	5
4	2.73	2.97	9	6	10	6
6	5.20	5.67	10	7	10	6
8	7.91	--	11	8	11	7
10	11.70	--	12	8	--	--

Costs for these piping materials are presented in Table 10.17. As a result of the high costs for CPVC, it has seen little application in geothermal systems.

Table 10.17 Costs for PVC and CPVC Pipe and Fittings (Means, 1996)

Size (in.)	PVC Sch. 40 ($/lf)	CPVC Sch. 40 ($/lf)	90 Degree Ell PVC ($ ea)
2	1.42	4.27	2.45
3	2.08	8.22	5.25
4	2.68	11.06	9.40
6	4.68	22.36	30
8	7.70	--	77
10	15.04	--	--

Selected standards for PVC and CPVC piping are listed in Table 10.18. Maximum operating pressures are listed in Table 10.19.

Table 10.18 PVC and CPVC Piping Specifications and Standards

Standard	Description
ASTM D 1784	PVC and CPVC Compounds - Rigid
ASTM D 1785	PVC Plastic Pipe Schedule 40, 80, and 120
ASTM D 2464	Threaded PVC Plastic Pipe Fittings Schedule 80
ASTM D 2466	Threaded Type PVC Plastic Pipe Fittings Schedule 40
ASTM D 2467	Socket Type PVC Plastic Pipe Fittings Schedule 80
ASTM D 2564	Solvent Cements for PVC Plastic Pipe and Fittings
ASTM F 438	Socket Type CPVC Plastic Pipe Fittings Schedule 40

Table 10.19 Maximum Operating Pressure for PVC and CPVC Pipe at 73°F

Size	Max. Pressure (psi)
2	230
3	260
4	220
6	180
8	160

10.2.6 Polyethylene (PE)

Polyethylene is in the same chemical family (polyolefin) as polybutylene and is similar in physical characteristics. It is a flexible material available in a wide variety of sizes from 0.5 to 42 in. diameter. To date, this material has seen little application in direct-use geothermal systems, primarily because of its maximum service temperature of 140 to 150°F. This maximum temperature is a rule of thumb recommended by the manufacturer (Phillips - Drisco Pipe, 1981). The piping is recommended only for gravity flow applications above this temperature. Very high molecular weight/high density PE can be employed for low pressure applications up to temperatures as high as 175°F. The SDR (standard dimension ratio--a wall thickness description) requirements under these conditions, however, greatly reduce the cost advantages normally found in polyethylene. Use of the material in geothermal applications has been limited to small diameter (0.5 to 1 in.) tubing employed for bare tube heating systems in greenhouses and snow melting.

Some European district heating systems are using a cross-linked PE product for branch lines of 4 in. and under. This material is servicable to 194°F at a pressure of approximately 85 psi. This product is currently available only in a pre-insulated configuration as discussed under Section 10.3.

Joining methods for polyethylene pipe is limited to thermal fusion.

Table 10.20 presents typical physical properties for polyethylene piping.

Table 10.20 Physical Properties of Polyethylene Piping

Property	Value
Coefficient of expansion	8.0 x 10^{-5} in./in. °F
Thermal conductivity	2.7 Btu in./h ft^2 °F
Specific gravity	0.957
Hazen-Williams flow factor	155

The pressure ratings of polyethylene piping are a function of SDR and temperature. Table 10.21 outlines typical ratings.

Support spacing is dependent upon line size, temperature and SDR as indicated in Table 10.22.

Table 10.21 Pressure Ratings (in psi) for Polyethylene Piping

Temperature	SDR			
(°F)	21	17	13.5	11
50	90	113	145	180
80	76	95	122	150
100	63	79	101	125
120	50	63	80	100
140	40	50	64	80

Table 10.22 Support Spacing for Polyethylene Piping

	SDR 11	
Size (in.)	73°F (ft)	125°F (ft)
2	4	3
4	5	4
6	6	5
8	7	6
10	8	7

Costs for polyethylene piping are shown in Table 10.23.

Table 10.23 Costs for Polyethylene Pipe (Means, 1996)

Size (in.)	SDR	Cost ($/lf)
1/2	11	0.17
3/4	11	0.25
1	11	0.38
1-1/4	11	0.69
1-1/2	11	0.85
2	11	1.92
3	11	2.27
4	11	3.91
6	11	3.95
8	11	14.90

Appropriate specifications and standards for polyethylene pipe are listed in Table 10.24.

Table 10.24 Polyethylene Pipe Specifications and Standards

Standard	Description
ASTM D 1248	Polyethylene Plastic Molding and Extrusion Materials
ASTM D 3350	Polyethylene Plastic Pipe and Fittings Materials
ASTM D 2447	Polyethylene (PE) Plastic Pipe, Schedules 40 and 80 Based on Controlled OD
ASTM D 2683	Socket-Type Polyethylene Plastic Pipe (SDR-PE) Based on Controlled OD
ASTM D 3261	Butt Fusion Polyethylene (PE) Plastic Fittings for Polyethylene Plastic Pipe and Tubing
ASTM D 2321	Underground Installations of Flexible Thermoplastic Sewer Pipe
AWWA C-901	Polyethylene (PE) Pressure Pipe 0.5 in. through 3 in. for Water

10.2.7 Copper

Copper piping, one of the most common materials in standard construction, is generally not acceptable for geothermal applications. Most resources contain very small quantities of hydrogen sulfide (H_2S), the dissolved gas that results in a rotten egg odor. This constituent is very aggressive toward copper and copper alloys. In addition, the solder used to join copper has also been subject to attack in even very low total dissolved solids (TDS) fluids. For these reasons, copper is not recommended for use in systems where it is exposed to the geothermal fluid.

10.2.8 Crosslinked Polyethylene (PEX)

Crosslinked polyethylene is a high-density polyethylene material in which the individual molecules are “crosslinked” during the production of the material. This can be accomplished by the use of peroxides, “A20" componds or exposure to electron bean according to ASTM F 876-70 “Specification for Crosslinked Polyethylene (PEX) Tubing.”

The affect of the crosslinking imparts physical qualities to the piping which allow it to meet the requirements of much higher temperature/pressure applications than standard polyethylene material. PEX piping carries a nominal rating of 100 psi @ 180°F. Table 10.25 summarizes ratings at other conditions.

Table 10.25 PEX Pressure Ratings (SDR 9)

Temperature	Pressure Rating (psi)
73	160
180	100
200	80

Physical characteristics of the material are summarized in Table 10.26.

Table 10.26 PEX Physical Properties

Coefficient of thermal expansion	8.0 x 10^{-5} in./in. °F
Thermal conductivity	2.7 Btu·in./hr·ft^2 °F
Specific gravity	0.952
Hazen-Williams flow factor	155

Joining the piping is accomplished through the use of specially designed, conversion fittings which are generally of brass construction. Since the piping is designed primarily for use in hydronic radiant floor heating systems, a variety of specialty manifolds and control valves specific to these systems are available.

The tubing itself is available generally in sizes of 4 in. and less with the 3/4 in. and 1 in. diameter most com-mon. Piping with and without an oxygen diffusion barrier is available. The oxygen barrier prevents the diffusion of oxygen through the piping wall and into the water. This is a necessary corrosion prevention for closed systems in which ferrous materials are included.

Larger sizes of the PEX material are available as either bare or pre-insulated. The pre-insulated product is sold in rolls and includes a corrugated polyethylene jacket and a closed-cell polyethylene insulation. Rubber end caps are used to protect the exposed insulation at fittings. The flexible nature of the pre-insulated product offers an attractive option for small-diameter distribution and customer service lines in applications where it is necessary to route the piping around existing utility obstacles.

Table 10.27 presents cost information for bare PEX piping. This information does not include fittings.

Table 10.27 PEX Piping Costs ($/ft)

Size	With O_2 Barrier	Without O_2 Barrier
3/4	1.65	1.35
1	3.30	2.50
1 1/4	4.25	3.10
1 ½	5.75	4.21
2	9.10	5.40
2 ½	--	7.65
3	--	10.60

PEX piping is covered under ASTM F 876-90 "Standard Specifications for Crosslinked Polyethylene (PEX) Tubing."

10.3 PRE-INSULATED PIPING SYSTEMS

Most district heating systems or long transmission lines carrying warm geothermal fluid will require some form of insulation. This insulation can be provided by selected backfill methods, field applied insulation or, more commonly, a pre-insulated piping system.

As shown in Figure 10.10, the pre-insulated system consists of a carrier pipe, through which the fluid is transported, an insulation layer, and a jacket material.

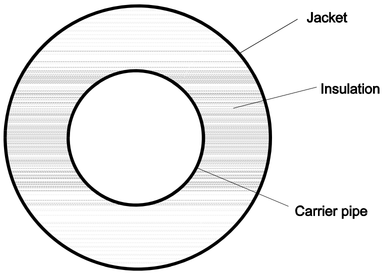

Figure 10.10 Pre-insulated piping system.

There is a wide variety of combinations available in terms of jacket and carrier pipe materials. The only common factor among most products is the use of polyurethane for the insulation layer. This insulation is generally foamed in place using a density of approximately 2 lb/ft^3 and a compressive strength of 25 psi. Thermal conductivity of the polyurethane varies, but a mean value of 0.18 Btu in./h ft^2 °F at 150°F is generally specified.

AC pre-insulated systems generally employ AC materials for both the carrier pipe and the jacket. Carrier piping is as described in the AC section above. The jacket material is usually a class 1500 sewer pipe product (ASTM C 428).

For steel, FRP, PB, PE, DUC, and PVC a variety of jacket materials are available. These include polyethylene, PVC, and fiberglass.

The most common material is PVC. High impact type piping is employed for this service with a minimum thickness of 120 mil.

Polyethylene jacketing material is commonly found on the European steel district heating lines and is generally a minimum of 125 mil. It is also used in corrugated form for the jacketing on pre-insulated PEX pipe.

Fiberglass jacketing is used primarily with fiberglass and steel carrier material.

Most jacketed systems (except fiberglass) employ a rubber end seal to protect the insulation from exposure to moisture. On fiberglass systems, the jacketing material is tapered at the end of each length to meet the carrier pipe, thereby forming a complete encasement of the insulation.

Most systems employ a 1- to 2-in. insulation layer, with fittings often left uninsulated.

Tables 10.28, and 10.29 presents cost data for selected examples of pre-insulated piping systems.

Table 10.28 Cost Data Pre-insulated Piping System

	Size			
Carrier Jacket	3 in. ($/lf)	4 in. ($/lf)	6 in. ($/lf)	8 in. ($/lf)
Steel/PVC	13.18	17.50	29.50	32.75
FRP/PVC (adhesive)	13.50	17.50	25.25	40.50
FRP/PVC (mechanical)	17.50	21.75	31.25	40.00
PVC/PVC (Schedule 40)	5.75	8.25	11.50	15.75
DUC/PVC	16.00	16.75	18.75	25.00

Table 10.29 Cost for Flexible Small Diameter Pre-insulated Tubing - PEX Carrier/PE Jacket

Size (in.)	Single Tube ($/lf)	Double Tube ($/lf)
3/4	18	25
1	21	31
1 1/4	27	39
1 ½	33	58
2	42	__
2 ½	55	__
3	60	__

10.4 INSTALLATION METHODS

Buried or aboveground pipe installations are options in the system design that require evaluation. Aboveground installations typically are supported on concrete pipe supports and rollers. This installation eliminates conflicts with buried utilities and may be easier to maintain. However, aboveground installations are more subject to damage and vandalism. Pipe supports and constraints, road crossings, venting, expansion provisions, and insulation protection are important considerations in the aboveground design.

Buried piping systems, the most common type of transmission line, are aesthetically more pleasing than aboveground installations and are deemed far superior from the standpoint of immunity to accidental or intentional damage. Major disadvantages are external pipe corrosion and accessibility for maintenance or service connections. Proper pipe bedding materials, grading, venting, expansion provisions, and corrosion protection should be reviewed for buried installations. Proper bedding is particularly important for the nonmetallic materials.

A method of buried installation that allows accesssibility is the use of utility tunnels with removable covers or adequate crawl space and manholes. This system is being used successfully for district heating systems in Iceland and Klamath Falls, Oregon (Karlsson, 1982; Lienau, 1984). It is also common on college campuses, military facilities, and conventional district heating systems. This type of piping is the most expensive and also the one with the longest life expectancy and lowest maintenance cost of all pipelines. Because of the high initial cost, this type is generally not used unless the line is relatively short or the consumer market is large. In an area being newly developed, this method can be used for a number of utilites. The system merits should be carefully evaluated and cost-to-benefits analyzed.

Pipe expansion and stress resulting from temperature changes should be allowed for in the piping system design. Adequate thrust blocking and restraints are needed to secure some kinds of pipe. Steel pipe should have expansion loops or expansion joints and thrust blocking to control the expansion and keep the pipe stress within the allowable limits. During the system layout, a comprehensive stress anaysis should be performed to determine if all sections of the system are within the allowable stress limits. The AC, ductile iron, and other types of push-on joints may allow for expansion in the joint and require only thrust blocks.

Another consideration is the head loss in a system. As the pipe size is decreased for a given fluid flow, the head loss will increase, therefore, increasing the pump motor size and energy consumption. Head loss in a piping system is a function of the quantity (gpm) circulated and the friction loss in the pipe.

Pipeline head loss should be carefully calculated using the manufacturer's flow data and corrected for the temperature involved. Because of the variation in flow characteristics for the materials covered in this chapter, it is not possible to cover data for all piping products. It is recommended that the Darcy-Wiesbach method be used for pipeline calculations.

The successful geothermal pipeline layout should consider the topography of the system. Distribution networks and transmission mains with significant changes in elevaltion may require additional venting and vacuum valves. Non-condensible gasses trapped at system high points can restrict flow rates and increase pumping requirements. If the water is drained from a pipeline without proper air venting, low pressure can be created that can cause the transmission line to collapse. Hot water has a higher vapor pressure and the problems associated with water flashing should be addressed.

10.5 UNINSULATED PIPING

High initial capital costs are one reason development has lagged in the area of district heating. Much of this cost (40 to 60%) is associated with the installation of the distribution piping network. The use of uninsulated piping for a portion of the distribution offers the prospect of reducing the piping material costs by more than 50%.

Although the uninsulated piping would have much higher heat loss than insulated lines, this could be compensated for by increasing system flow rates. The additional pumping costs to maintain these rates would be offset by reduced system capital costs. Preliminary analysis indicates that it would be most beneficial to use uninsulated lines in sizes above about 6 in. in certain applications.

It is important before discussing the specifics of uninsulated piping to draw a clear distinction between heat loss (measured in Btu/hr lf) and temperature loss (measured in ^{o}F/lf). Heat loss from a buried pipeline is driven largely by the temperature difference between water in the pipe and the ambient air or soil. The temperature loss which results from the heat loss is a function of the water flow in the line. As a result, for a line operating at a given temperature, the greater the flow rate the lower the temperature drop. In geothermal systems, the cost of energy is primarily related to pumping; this results in a low energy cost relative to conventional district systems and the ability to sustain higher energy losses (of the uninsulated piping) more economically.

Figure 10.11 illustrates the relationship of flow rate and temperature loss. The figure is based upon 6 in. preinsulated (1.8 in. insulation, PVC jacket, FRP carrier pipe) and a 6-in. uninsulated pipe buried 4 ft below the ground

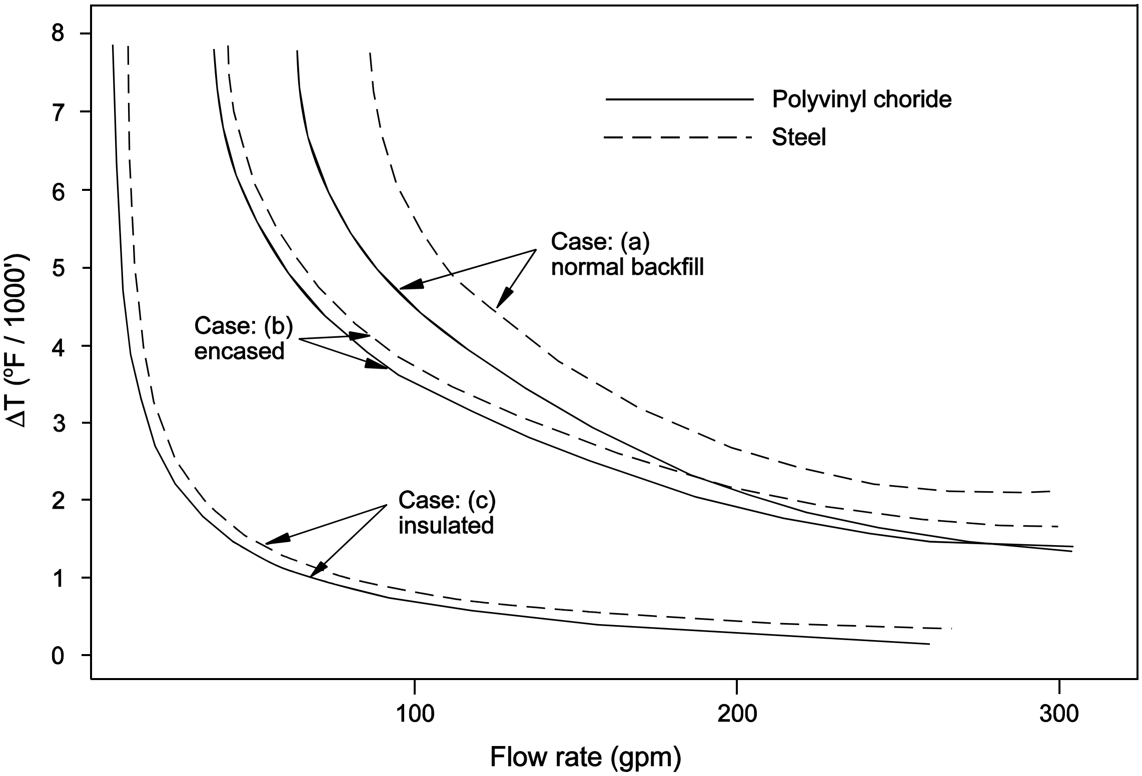

Figure 10.11 Buried pipeline temperature loss versus flow rate (Ryan, 1981).

and operating at 170ºF inlet temperature. Temperature loss per 1,000 ft is plotted against flow rate. As discussed above, the graph indicates the substantial increase in temperature loss at low flow rates.

The nature of the relationship shown in Figure 10.11 suggests that it may be possible in some applications to adequately boost flow through a line to compensate for temperature loss in an uninsulated line. A temperature control valve could be placed at the end of line which could direct some flow to disposal to maintain acceptable temperature.

The prospect for the use of uninsulated piping is greatest for larger sizes (>6 in.). This is related to the fact that in larger sizes the ratio of the exposed surface area (pipe outside surface area) compared to the volume (flow capacity) is reduced. This relationship reduces the heat lost per gallon of water passed through the line.

If the use of uninsulated piping is to be economically attractive, a high load factor (total annual flow divided by peak flow) is required. In many district systems, initial customer flow requirements amount to only a small fraction of the distribution capability. Many years are required for the system to approach full capacity. Under these conditions, the system is operated at very low load factor initially and the economics of uninsulated piping would likely not prove to be favorable.

Systems designed for an existing group of buildings or those which serve process loads are more likely candidates for the use of uninsulated piping.

Table 10.30 presents the results of an example of uninsulated pipe used for a specific case. The table is based on the following:

1. 6 in. fiberglass pipeline
2. 170ºF water temperature
3. 4 ft burial depth
4. Soil conductivity = 10 Btu in./h·ft^2 ºF
5. Design velocity 5 ft/sec (450 gpm)
6. Minimun flow = 15% of design (68 gpm)
7. Minimum flow occurs at temperatures above 60ºF
8. Between 0º (design temperature) and 60ºF a linear reduction in flow occurs (from 450 to 68 gpm)
9. Average well pump efficiency = 0.63
10. Pumping level = 200 ft
11. Well head pressure requirement = 40 psi
12. Electricity costs $0.07/kWh
13. Allowable temperature drop = 2ºF
14. Line length = 1,500 ft.

Column 1 contains the outside temperature values. Column 2 contains the annual number of hours at each outside temperature. Column 3 provides the system flow requirement at each outdoor temperature. The temperature

Table 10.30 Uninsulated Pipe with a Base Loss of 140.6 Btu/hr lf

1 Outside Air Temp. °F	2 hrs/yr	3 Flow gpm	4 Δt °F	5 for 2° Δt	6 Flow flow gpm	7 Excess Pump kW	8 Annual kWh
2	17	450	0.94	--	0	0	0
7	39	414	0.98	--	0	0	0
12	82	374	1.05	--	0	0	0
17	150	338	1.12	--	0	0	0
22	352	302	1.22	--	0	0	0
27	675	261	1.36	--	0	0	0
32	1132	225	1.52	--	0	0	0
37	1044	189	1.75	--	0	0	0
42	931	149	2.13	159	10	.873	813
47	826	113	2.70	153	39	3.460	2706
52	783	77	3.80	146	69	6.050	4743
57	658	68	4.12	140	72	6.300	4145
62	551	68	3.94	134	66	5.760	3173
67	468	68	3.76	128	60	5.220	2442
72	373	68	3.58	122	54	4.710	1758
77	313	68	3.40	115	47	4.130	1294
82	235	68	3.21	109	41	3.600	845
87	124	68	3.02	103	35	3.050	379
92	39	68	2.85	97	29	2.510	98
	8792						22,396

22396 kWh @ $0.07/kWh = $ 1,568/yr
1500 lf X $10/lf savings = $15,000

drop across the line for each temperature appears in Column 4. The required flow to maintain a 2°F temperature drop appears in Column 5. Column 6 is the excess flow (above system requirements) to maintain a 2°F temperature drop. Column 7 shows the required well pump kW to pro-vide the excess flow. Column 8 indicates the total annual kWh consumption for temperature maintenance for each outside temperature.

In this particular case, the elimination of insulation on the 1,500 ft, 6 in. line would save approximately $15,000 in capital costs. The first year cost of electricity to compensate for the lack of pipe insulation amounts to $1,568.

Assuming the owner was financing the project at 9% for 20 years and that electricity inflates at 7% per year, the simple payback on the insulation for the pipe is in excess of 15 years.

10.5.1 Items Important to the Consideration of Uninsulated Piping:

1. Cost of Pumping. This is influenced primarily by the overall pumping system efficiency, cost of electricity, well pumping level, well head pressure requirements, and pump capacity control (throttling valve, variable speed drive, etc.). As the unit cost of pumping increases, the attractiveness of uninsulated pipe decreases.

2. System Load Factor. The higher the load factor, the more practical uninsulated piping becomes. Higher system load factor reduces the quantity of excess water which must be pumped to maintain supply temperatures.

3. Allowable Temperature Drop. The more tempera-ture which can be sacrificed, the greater the possi-bility to use uninsulated piping. Allowable tempera-ture drop must be carefully balanced against resource temperature and customer needs. In the ex-ample, had a 3°F rather than 2°F drop been accept-able, annual pumping costs for temperaure maintenance would have been reduced from $1,568 to $369 per year for the line. A four degree drop would have eliminated excess pumping completely.

4. Proximity of Other Utilities. Close proximity to some telephone, electric or water utility lines may preclude the consideration of uninsulated lines due to temperature effects.

5. Disposal Method. It is apparent from the example that most excess flow requirements occur during the summer months. If surface disposal is employed, low surface water flows (rivers) may influence the maximum rate of geothermal disposal based on chemical or thermal pollution.

6. Customer Contract. Allowance for lower temperature supply water during the warmer portion of the year could reduce the requirement for excess pumping for temperature maintenance.

7. Piping Type. The use of uninsulated piping may be unpractical for steel and ductile iron. These materials would likely require exterior protection if uninsulated. This would reduce the savings achieved through the use of uninsulated pipe.

8. Local Soil Conditions. Soils of high thermal conductivity or wet areas tend to increase heat loss from piping. These areas would reduce the potential for uninsulated piping.

9. System Water Temperature. Lower temperature systems may be better candidates for uninsulated pipe use.

10. Line Size. As discussed earlier, larger lines (>6 in.) are more likely to yield positive results with respect to the use of uninsulated pipe.

10.6 COST ISSUES IN GEOTHERMAL DISTRICT HEATING DISTRIBUTION

A recent report (Rafferty, 1996) evaluated some of the cost associated with geothermal distribution piping in the context of the applications in which it is often applied in the western U.S. The work involved characterizing the various components of the cost of installing distribution piping in developed areas and the potential for reducing these costs in an effort to serve single-family homes with geothermal district heating (Table 10.31).

Cost for installation of preinsulated distribution piping were broken down into 11 categories: saw cutting of existing pavement, removal of pavement and trench spoils, hauling of pipe (local), trenching and backfill, pipe material, bedding, installation and connection of piping, valves, fittings, traffic control, and paving. Each of these areas is discussed briefly below.

Saw cutting of existing pavement is necessary when the pipe installation is to be below a street or other paved surface. The operation consists of a single operator and a walk behind, self-propelled, gas-powered saw. Values used in this calculation assume: two parallel cuts in 4-in. thick asphalt over the trench.

Pavement removal occurs prior to trenching and after saw cutting. Depending upon the local conditions, it may be part of the trenching operation. This would be deter-mined by the disposal used for the paving material. If disposal is possible at the same site a the trench spoils, costs for this operation may be reduced or eliminated. The assumption in Table 10.31 is that the paving material must be disposed of separately from the trench spoil.

Hauling of pipe is generally required when working in urban areas. Piping material is stockpiled at a location other than the actual installation site. Hauling is necessary to move the pipe from the contractor's equipment yard to the installation site.

Trenching and backfilling are major cost components of the piping installation. The cost is heavily influenced by

Table 10.31 Base Case Cost Summary ($/lf) - Ductile Iron Distribution Piping

	Line Size (Supply and Return)					
	3"	4"	6"	8"	10"	12"
Cut	4.12	4.12	4.12	4.12	4.12	4.12
Remove	2.20	2.20	2.57	2.57	2.90	2.90
Haul	0.71	0.71	0.83	1.14	1.37	1.71
Trench and Backfil	8.83	8.83	10.01	10.01	16.31	16.31
Bed	2.57	2.65	3.84	3.87	3.98	4.06
Pipe (preinsulated)	27.18	30.75	34.23	45.48	57.63	64.41
Install	10.68	12.53	14.38	22.31	26.45	33.00
Fittings	3.00	3.00	4.17	6.02	8.60	11.15
Valves	1.95	1.95	2.73	4.07	6.13	9.23
Thrust Blocks	0.37	0.37	1.22	2.81	4.44	6.22
Traffic	3.09	3.43	3.93	4.58	5.50	6.87
Repave	10.66	10.66	12.48	12.48	14.08	14.08
Total	75.36	81.20	94.51	119.46	151.51	174.06

the presence of other utilities in the pipeline corridor. Costs below are based upon trench widths of 36 in. wide for 3- or 4-in. lines, 42 in. for 6- and 8-in. lines, and 48 in. for 10- and 12-in. lines. Trench depth is 42 inches for lines up to 8 inches, and 60 inches for 10- and 12-in. lines. Soil is assumed to be stable (permitting vertical sides). Costs include trenching, backfilling, compaction and removal of spoil. A 50% penalty is added to account for working around existing utilities.

Pipe bedding is used to assure that the backfill material placed adjacent to the pipe is free of rocks and other objects which could cause damage to the casing or impede adequate compaction. Costs below assume the use of sand for bedding to a depth of 12 in. over the pipe. Compaction costs are included.

Pipe costs were based upon the use of preinsulated ductile iron supply and return lines. This material is the most common in recent extensions of existing systems.

Installation includes lowering the pipe into the trench and connecting each length to the next. The pipe material is Tyton-joint ductile iron. Joining consists of inserting the rubber gasket, applying lubrication and drawing the two lengths of pipe together. Labor is base on values for installation of distribution water mains.

Valves are used in water distribution systems to isolate major branches so that service can be performed without shutting the entire system down. The costs in the table incorporate non-rising stem gate valves (with valve boxes) at 500-ft intervals. The actual valve spacing is dependent upon individual system design.

Fitting cost is influenced by the design of the system, existing utility and customer density. The costs in the table are reflective of moderate customer density and light existing utility interference. These costs assume two elbows and two tees per 200 ft of line.

Thrust blocks are required on unrestrained piping systems at all changes in direction, valves, tees and caps. They serve to resist the forces developed by the water pressure and flow direction changes. Thrust blocks are constructed by pouring concrete between the fitting and undisturbed soil. The size of the block is function of the pipe size, line pressure, and soil type. The costs in the table assume 2000 lb/ft^2 soil bearing capacity and concrete costs of \$200 yd^3. Blocks are assumed to be used for all the fittings cited above.

Traffic control is required around open trenches and similar construction in or near a roadway. The traffic control assumed in the costs in the table is based upon two flaggers working eight hours per day. The variation in cost is due to the lower installation output (ft/day) for larger pipe sizes.

Paving is based on the placement of 4 in. of asphalt concrete over the trenches at a cost of \$32/yd^2.

Table 10.31 provides a summary of the base case costs for installation of preinsulated ductile iron piping for 3 through 12 in. sizes.

Installation of distribution piping in residential areas offers several opportunities for reducing these costs. Placing the pipeline under unpaved areas can reduce costs 12% (12 in.) to 22% (3 in.) by eliminating costs associated with saw cutting, removing and repaving the area. The use of uninsulated return piping offers the prospect for modest savings in the smaller pipe size range. Assuming the use of uninsulated fiberglass (epoxy adhesive joining) to replace the return lines, a savings of 9.3% in 3 in., 8.9% in 4 in., and 2.5% in 6 in. sizes can be made. In larger pipe sizes, the cost of the bare fiberglass material exceeds that of the preinsulated DI.

If no existing buried utilities are located along the pipeline route, a savings of 3% to 4% (depending upon the line size) can be achieved through reduced trenching costs.

Traffic control during construction is almost always necessary in downtown areas. It is possible that some or all active traffic control could be eliminated in residential areas by simply closing the area under construction. Elimating the labor for active traffic control offers a savings of approximately 4% over the range of line size (3 in. - 12 in.) covered in this report.

Using all of the above potential reductions results in the savings summarized in Table 10.32.

Table 10.32 Summary of Potential Cost Reduction - Distribution Piping

Size	Base Cost (\$/lf)	Lowest Cost (\$/lf)	% Reduction
3"	75.36	45.85	39.2
4"	81.20	51.63	36.4
6"	94.51	68.07	28.0
8"	119.46	92.37	22.7
10"	151.51	119.47	21.1
12"	174.06	140.64	19.2

10.7 BURIED PIPELINE HEAT LOSS

The heat loss for the line various conditions should be calculated to determine the buried pipeline heat loss, using:

$$\frac{q}{l}=\frac{\dfrac{\Delta T}{l}}{\dfrac{1}{2\pi}\left(\dfrac{\ln\dfrac{r_2}{r_1}}{k_1}+\dfrac{\ln\dfrac{r_3}{r_2}}{k_2}+\dfrac{\ln\dfrac{r_4}{r_3}}{k_3}+\dfrac{\ln\left[\dfrac{d}{r_4}+\left(\dfrac{d}{r_4}-1\right)^{-2}\right]}{k_4}\right)}$$

where

$\frac{q}{l}$ = *heat loss pipe, Btu/h lf*

ΔT = design temperature difference between soil surface temperature and fluid in pipe (°F)

r_1 = radius of carrier pipe ID (in.)
r_2 = radius of carrier pipe OD (in.)
r_3 = radius of jacket pipe ID (in.)
r_4 = radius of jacket pipe OD (in.)

d = buried depth of pipe to center line (in.)

k_1 = thermal conductivity of carrier pipe (Btu in./h ft^2 °F)
k_2 = thermal conductivity of insulation (Btu in./h ft^2 °F)
k_3 = thermal conductivity of jacket pipe (Btu in./h ft^2 °F)
k_4 = thermal conductivity of soil (Btu in./h ft^2 °F)

The use of this equation is most easily demonstrated through the use of a typical example. Assume a preinsulated 8 in. FRP line is installed according to the diagram in Figure 10.12.

Substituting the values into the above, we have:

q = 33.7 Btu/h lf.

For an uninsulated line, the expressions relating to the insulation and jacket would simply be eliminated. It should be pointed out that this method is somewhat conservative for two reasons: (a) it assumes a steady state situation, and (b) it ignores the conductance of the ground surface film. Both of these would tend to reduce the actual heat loss from the line. However, because the effect of these items is relatively small, they can safely be omitted for design purposes.

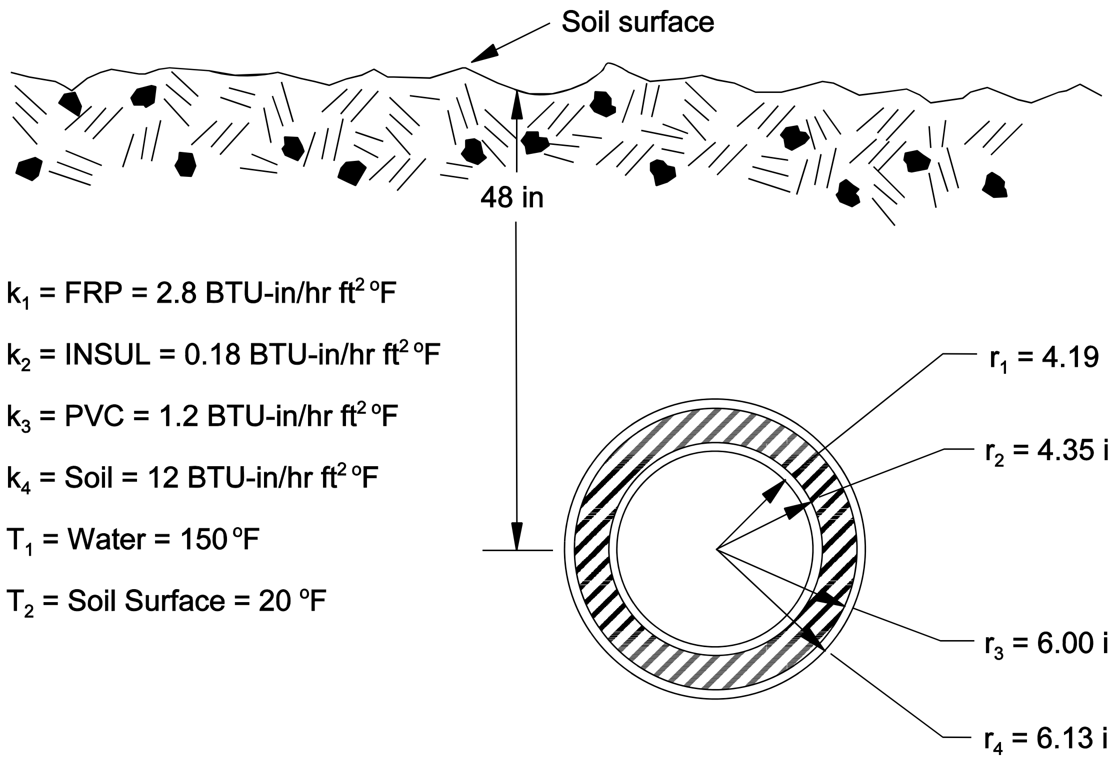

Figure 10.12 Data for preinsulated fiberglass pipe.

REFERENCES

Austin, J. C., 1980. "Transporation and Distribution of Geothermal Fluids," Commercial Uses of Geothermal Heat, Special Report No. 9, Geothermal Resources Council, Davis, CA.

Celanese Piping Systems, Inc., 1976. Chemtrol Thermo-Plastic Pipe and Fittings Catalog, Bulletin #319, Celanese, Inc. Hilliard, OH.

Ellis, P. and P. Conover, 1981. "Materials Selection Guidelines for Geothermal Energy Utilization Systems," USDOE (DOE RA270266-1), Washington, DC.

Fisher, K., 1987. Personal communication. San Bernardino Water Department, San Bernardino, CA.

Johns Mansville, 1982. Temp-tite Catalog #CH-8, Johns Mansville, Denver, CO.

Karlsson, T., 1982 "Geothermal District Heating, The Iceland Experience," UNU Geothermal Training Program, University of Iceland, Reykjavik, Iceland.

Khashab, A. M., 1984. HVAC System Estimating Manual, McGraw-Hill Book Co., New York.

Lienau, P. J., 1984. "Geothermal District Heating Projects," District Heating, Vol. 70, No. 1 & 2, International District Heating Association, Washington, DC.

Means, 1989 and 1996. Mechanical Cost Data, R. S. Means Company, Inc., Kingston, MA.

Phillips - Driscopipe Inc., 1981. Driscopipe Systems Design, Richardson, TX.

Rafferty, K., 1989. “Geothermal District Piping - A Primer,” Geo-Heat Center, Klamath Falls, OR.

Rafferty, K., 1996. “Selected Cost Considerations for Geothermal District Heating in Existing Single-Family Residential Areas,” Geo-Heat Center, Klamath Falls, OR.

Ryan, G. P., 1981. "Equipment Used in Direct Heat Projects," Geothermal Resources Council Transactions, Vol. 5, Davis, CA, pp. 483-486.

Smith-Inland, Inc., 1982. "Engineering and Design Guide for Fiberglass Reinforced Piping Systems," A. O. Smith-Inland, Inc., Little Rock, AR.