PIPING

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INTRODUCTION

The source of geothermal fluid for a direct use appli-cation is often located some distance away from the user. This requires a transmission pipeline to transport the geo-thermal 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 expan-sion 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. 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 1 and 2 introduce the temperature limitations and relative costs of the materials covered in this article. Generally, the various pipe materials are more expensive the higher the temperature rating. Figure 2 includes 15% overhead and profit (O&P). Cost data in this article are based on Means 1996 Mechanical Cost Data.

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.

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.

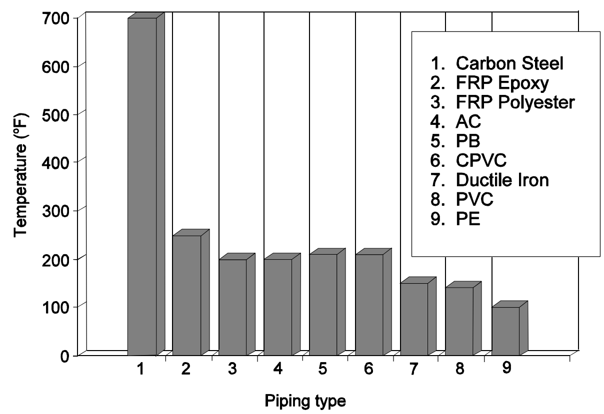

Figure 1 Maximum service temperature for pipe materials.

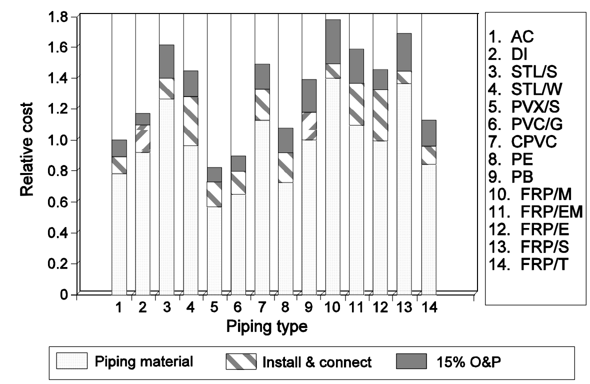

Figure 2 Relative cost of piping by type.

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. Asbestos cement (AC) material has been the most widely applied product; however, enviornmental concerns have limited its use and availability. A discussion of piping material currently in use in U.S. district heating systems appears in Rafferty (1989).

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.

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. 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 geother-mal 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

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. The potential for external corrosion of metallic pipe systems should be considered for all direct buried installations. Various soil types, presence of groundwater, 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). If unlined steel piping is employed on the geothermal 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 1.

Table 1. Steel Pipe Costs, Material Only

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

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. 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).

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 mortar 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 tempera-ture 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. 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 130ºF application would add $5.00 to $8.00/ lineal foot to the price of the pipe. 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 (<150ºF) system during shutdown periods.

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. However, ductile iron pipe is the heaviest material of those covered in this article. As a result, it would incur additional handing costs in comparison to the lighter weight materials. Table 2 outlines costs for ductile iron piping.

Table 2. Costs For - Ductile Iron Piping (Uninsulated - Tyton Joint)

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

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 200ºF.

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, including mechanical (keyed, threaded and flanged) and adhesive type jointing. Of these, the bell and spigot/adhesive has seen the widest application in geothermal systems.

In making the choice between the mechanical and ad-hesive 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 some-what 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 tempera-ture.

Below approximately 75ºF, 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.

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. 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.

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 3. It should be noted that fitting costs can constitute a substantial portion of the total cost for a piping system.

Table 3. Cost for Fiberglass Piping (epoxy lined/ adhesive type joint)

Size	Pipe	Fittings		
		Ell	Tee	Joint Kit
(in.)	($/lf)	($/ea)	($/ea)	($/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

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.

Table 4. Costs for PVC and CPVC Pipe and Fittings

Size	PVC	CPVC	90 Degree Ell
	Sch. 40	Sch. 40	PVC
(in.)	($/lf)	($/lf)	($ 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	--	--

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.

Costs for these piping materials are presented in Table 4. As a result of the high costs for CPVC, it has seen little application in geothermal systems.

Polyethylene (PE)

Polyethylene is in the same chemical family (poly-olefin) as polybutylene and is similar in physical character-istics. 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. The piping is recommended only for gravity flow applications above this temperature. Very high mol-ecular 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 de-scription) requirements under these conditions, however, greatly reduce the cost advantages normally found in polyethylene. Use of the material in geothermal applica-tions 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 approx-imately 85 psi. This product is currently available only in a pre-insulated configuration as discussed later in this article.

Joining is limited to thermal fusion of polyethylene pipe. The pressure ratings of polyethylene piping are a function of SDR and temperature. Costs for polyethylene piping are shown in Table 5.

Table 5. Costs for Polyethylene Pipe

Size		Cost
(in.)	SDR	($/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

Copper

Copper piping, one of the most common materials in standard construction, is generally not acceptable for geo-thermal 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 aggres-sive 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.

Crosslinked Polyethylene (PEX)

Crosslinked polyethylene is a high-density poly-ethylene material in which the individual molecules are "crosslinked" during the production of the material. 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.

Joining the piping is accomplished through the use of specially designed, conversion fittings which are generally of brass construction. Since the piping is designed primar-ily for use in hydronic radiant floor, sidewalk and street (snow melting) 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 corrogated 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 attrac-tive option for small-diameter distribution and customer service lines in applications where it is necessary to route the piping around existing utility obstacles.

Table 6 presents cost information for bare PEX piping. This information does not include fittings.

Table 6. 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

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.

The pre-insulated system consists of a carrier pipe, through which the fluid is transported, an insulation layer, and a jacket material.

There is a wide variety of combinations available in terms of jacket and carrier pipe materials. The only com-mon 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 com-pressive 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 corrogated 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 7 and 8 presents cost data for selected examples of pre-insulated piping systems.

Table 7. 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 8. 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	__

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 compen-sated 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 un-insulated piping to draw a clear distinction between heat loss (measured in Btu/hr lf) and temperature loss (measured in ^oF/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 con-ventional district systems and the ability to sustain higher energy losses (of the uninsulated piping) more economic-ally.

Figure 3 illustrates the relationship of flow rate and temperature loss. The figure is based upon 6 in. pre-insulated (1.8 in. insulation, PVC jacket, FRP carrier pipe) and a 6-in. uninsulated pipe buried 4 ft below the ground and operating at 170^{o}F 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.

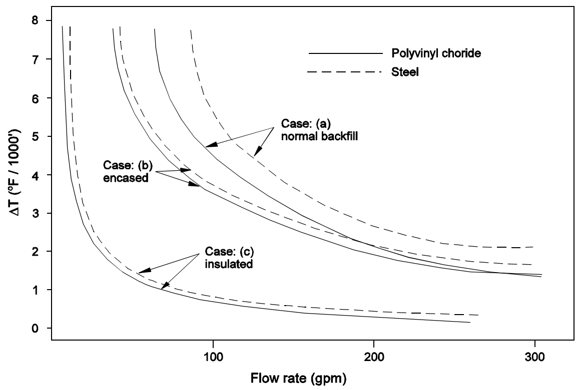

Figure 3. Buried pipeline temperature loss versus flow rate (Ryan, 1981).

The nature of the relationship shown in Figure 3 suggests that it may be possible in some applications to adequately boost flow through a line to compensate for tem-perature 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 condi-tions, 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 candi-dates for the use of uninsulated piping.

REFERENCES

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

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

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