TRANSPORTATION AND DISTRIBUTION OF GEOTHERMAL FLUIDS

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ABSTRACT

Transportation of geothermal fluids through pipelines from well heads to the energy user is common in most geothermal applications. Several factors including pipe material, size and installation, insulation, and pumping should be considered when designing the transmission pipeline or comparing system economics. This paper addresses some of the technical aspects which should be considered prior to final system selection.

INTRODUCTION

Exploitable geothermal energy is characterized as being very site-specific. Its occurrence is governed by numerous geologic factors which often limit its presence to geographic regions which are sparsely populated or undeveloped. A majority of the resource occurs in the liquid phase or liquid/vapor phase at temperatures ranging from 70°F to 400°F. Only a few geothermal regions have resources at temperatures high enough to be in the vapor dominated or steam phase such as The Geysers in Northern California.

In the low and medium temperature liquid resources, the energy which can be extracted is limited to the specific heat of the geothermal water (1 British thermal unit per pound per degree Fahrenheit or 1 Btu/lb °F). In a typical geothermal system, 415 Btu/gallon of water can be extracted with a 50°F temperature change. This compares to 141,000 Btu/gallon for No. 2 fuel oil. In applications where large amounts of energy are required from low temperature resources, the economics of transporting the fluid over long distances must be critically reviewed. As the fluid flows through a pipeline or is stored in a tank, it also loses temperature and usable energy. Proper insulation can reduce this energy loss; however, at best, geothermal energy transported or stored outside the reservoir must be utilized in a short time before its heat is dissipated.

In several installations, long transmission mains appear to be economically feasible. Geothermal fluids are being transported more than 10 miles in Iceland,[1] and a 45-mile-long 42-inch diameter pipeline is being considered by Northwest Natural Gas between Mt. Hood and Portland, Oregon.[2]

Geothermal energy usually is transported in the liquid phase and has some of the same design considerations as water distribution systems including pumping, installation of pipe, metering, service taps, etc. In addition, geothermal waters possess some unique design considerations such as dissolved chemical components, temperature, insulation, pipe expansion, and disposal of spent fluids. These varying aspects of geothermal fluids make each system design unique. The aspects of the geothermal system presented here are limited to transportation and distribution considerations.

PIPE MATERIALS

Typical water pipe materials presently used are steel, cast iron, asbestos cement (AC), fiberglass reinforced (FRP), and certain plastics. In systems below 180°F, any of these materials will perform satisfactorily except for the plastics which are limited to temperatures less than 170°F normally. In the higher temperature systems (above 230°F), most nonmetallic piping has not proven to be successful.

EG&G studies[3] and experience with 240°F geothermal water at the Raft River, Idaho project has demonstrated that asbestos cement pipe is susceptible to thermal shock. 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. AC pipe is performing satisfactorily in several low temperature (170°F) installations such as the State of Idaho Agricultural Laboratory.[4]

Fiberglass reinforced pipe is limited to temperatures of near 200°F at moderate pressures by some manufacturers. At higher temperatures, the FRP systems are susceptible to damage when the water flashes to vapor. The forces associated with the flashing may spall the interior pipe surface. In the system design, care must be taken to prevent the occurrence of flashing. Polyvinyl chloride (PVC) and polyethylene pipe are normally not recommended above the 150°F - 170°F range. The plastic pipe materials do perform well in the lower temperature ranges where pressures are not excessive.

Geothermal water chemistry can impact the type of pipe material selected. Under certain conditions, the bond cement may leach out of asbestos cement, exposing filament asbestos which can disperse in the fluid. Steels and cast iron pipe systems are subject to corrosion or scaling with certain water conditions. The impact of water chemistry can be reduced or eliminated by protective coatings and proper materials selection. Asbestos cement pipe, for example, can be obtained with an epoxy lining. Corrosion and scaling of metallic pipe can sometimes be controlled by elimination of air or oxygen in the system. Several material selection manuals[5] have been prepared which can be a design aid to the geothermal designer.

The potential for the external corrosion of metallic pipe systems should be considered. Various soil types, presence of ground water, induced current fields from powerlines, etc., may accelerate pipe corrosion and early system failure. Piping systems may be protected through the use of coatings such as polyethylene films, or cathodic protection. Often pipe failures are the first indication of a corrosion problem which results from improper material or lack of cathodic protection.[6]

AC, FRP, PVC, and polyethylene pipe systems are usually not susceptible to external corrosion or deterioration due to soil conditions. Their failures usually result from improper trench preparation, pipe bedding, backfill or surface loading.

The table compares the common pipe systems used in geothermal applications.

PIPE LOCATION

Buried or aboveground pipe installations may be options in the system design which 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 vehicle damage and sabotage. Pipe supports and constraints, road crossings, venting, expansion provisions, and insulation protection are important considerations in the aboveground design.

Buried piping systems 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 must be reviewed in buried installations.

A method of buried piping which allows accessibility is the use of utility tunnels. The pipe is installed in concrete or metal 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.[1,7] The pipelines are protected and accessible for future tapping and maintenance. The significant disadvantage with the utility tunnel system is the expense. The system merits should be carefully evaluated and the costs-to-benefits analyzed.

Pipe expansion and pipe stress resulting from temperature changes must be allowed for in the piping system design. Adequate thrust blocking and constraints are needed to secure the pipe. Some FRP manufacturers recommend thrust blocks and proper trench backfill materials with no expansion loops. Steel pipe must 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 analysis should be done to determine if all sections of the system are within the allowable stress limits. Several computer programs and other design aids are available to assist the designer. Asbestos cement and other types of push-on joints may allow for expansion in the joint and require only thrust blocks.

The successful geothermal pipeline layout must consider the topography of the system. Distribution networks and transmission mains with significant changes in elevation may require additional venting and vacuum valves. Noncondensible gases trapped at system highpoints can restrict flow rates and increase pumping requirements. If the water is drained from a pipeline without proper air venting, low pressures can be created which can cause collapse of the transmission main. The possibility of water hammer should be thoroughly investigated. Warm or hot water has a lower vapor pressure and the problems associated with water

PIPELINE MATERIALS COMPARISON TABLE

Material	Sizes, in.	Approximate Limiting Temperature °F	Joints	Expansion Loops	Service Taps	Hazen Williams Friction Factor C	Corrosion Protection
Cast Iron	3 - 20+	300°	Push-on	No	Good	110	Interior - none Exterior - tape wrap and cathodic protection in moist soils
Steel	3/4 - 20+	600°+	Welded	Yes	Good	120	Interior - as required Exterior - tape wrap and cathodic protection
Asbestos Cement	6 - 20+	230°	Push-on	No	Good	140	Interior - epoxy Exterior - none
PVC & Polyethylene	3/4 - 12	170°	Fusion Bonded or Push-on	No	Good	150	Interior - none Exterior - none
FRP	3/4 - 12	200°	Fusion Bonded	No	Fair	150	Interior - none Exterior - none

column separation (water flashing to vapor) are increased. Particular care should be taken to avoid low suction pressures for pumps, and valve and fitting configurations where cavitation could be experienced.

In distribution systems, a complete pipeline network analysis is advisable. An accurate analysis will indicate: 1) the areas where high or low pressures may be experienced, 2) where venting should be installed, and 3) the lateral main sizes to equalize pressure losses within the system.

PIPE INSULATION

Pipeline insulation is used primarily to conserve heat and provide protection for the pipe. Heat loss from a pipeline should be calculated according to methods developed by the National Bureau of Standards. The amount of energy or heat lost per gallon is directly proportional to the pipe diameter and inversely proportional geothermal flow rate.

Several different types of insulation systems are used in geothermal systems, ranging from preinsulated and jacketed pipe to insulations formed in the trench. Preinsulated and jacketed pipe systems have been extensively used in geothermal applications. These systems are available for AC, steel, plastic, and FRP pipe systems and have excellent integrity. Initial material costs for preinsulated systems may be greater than preformed and trench installed insulation systems. However, preinsulated systems can be less costly when installation costs are added to the materials cost. Field installed insulation is labor intensive and may result in less integrity due to poor installation conditions. Many of the preinsulated piping systems utilize urethane foam with a PVC jacket or AC pipe jacket. These jackets resist moisture penetration which is a major concern in areas where ground water is present. The insulating properties of most insulations are lost when water soaked.

Other insulation systems include fiberglass, closed cell glass, calcium silicate, and urethane, all of which come in preformed sections. These sections can be attached to the pipeline and then covered with a field applied PVC, asphalt impregnated cloth or metal jacket.

Nonwettable mineral powders have been used in some piping installations. Typically, they are poured around the pipe in the trench and then covered with backfill. Varying success has been reported with these systems which probably is a result of different manufacturers, contractor installation techniques, and the amount of soil moisture present.

Pipelines can be insulated in the field by using urethane foam applied to the pipeline after it is placed in the trench. This system has proven to be unacceptable in many cases. The outer layer of urethane may develop breaks due to backfill or expansion which allows water to enter and break down the insulation. Before urethane foam is used, the application should be carefully reviewed to ascertain low moisture conditions. Direct urethane foam systems are initially relatively inexpensive and have applications where the transmission line is temporary.

In some instances, no insulation may be the most economical approach. A cost analysis should be made to compare the heat conserved to insulation expense for the projected life of the project.

PIPELINE TAPS

In the evaluation of a piping system, consideration should be given to the ease of making modifications or future pipeline taps. If the pipeline serves a limited number of users and modifications are not anticipated, ease of tapping may not be a major concern. In a district heating system where future taps for users is a distinct possibility or other modifications may be necessary, pipe system type should be considered. Pipe tapping procedures for steel, cast iron, and asbestos cement systems are understood by most competent contractors and can be accomplished with little difficulty. Others like the FRP systems can be field tapped, but with some difficulty, by procedures not frequently used by maintenance personnel. In less than ideal conditions such as a wet, cold trench location, an improper tap or repair may be the source of future problems.

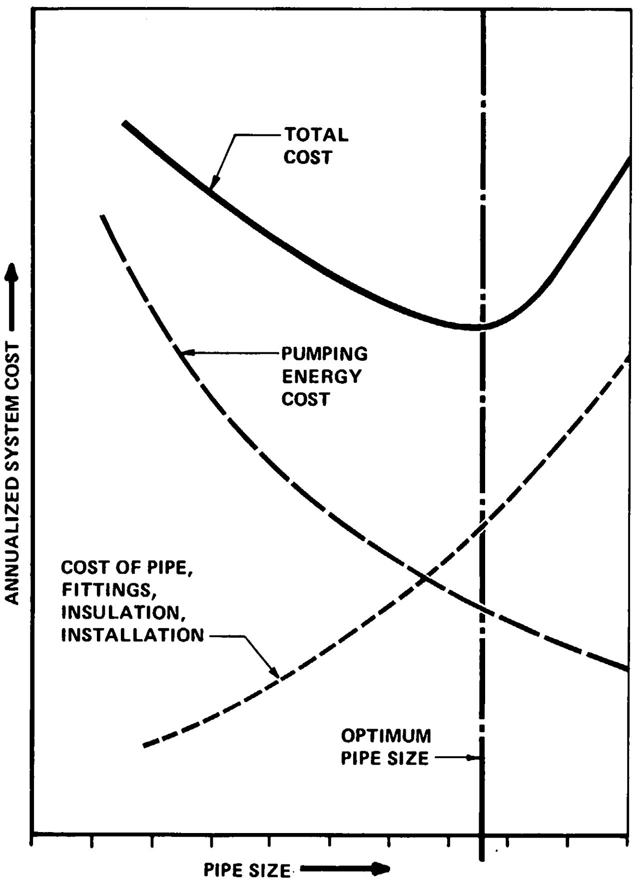
PUMPING COSTS

The pumping costs associated with a geothermal transmission or distribution system represent a significant annual operating cost over the lifetime of the system. Likewise, pipeline costs may be the major capital cost item in a new system. For example, in the proposed geothermal system in Boise, Idaho,[8] these costs run 30 percent or more of the total system cost. The pipeline sizing and material selection have a direct impact upon future pumping costs. These costs are proportional to the pipeline characteristics, according to the relationship.

Pumping Cost $\propto$ ($gpm^{2.85}$, $Dia.^{-4.87}$, $C^{-1.85}$) where gpm is the flow rate, D the pipe diameter, and C the Hazen and Williams friction factor.[9] This equation illustrates the high dependence pumping costs have on pipe diameter and friction factor or relative roughness of the pipe. The friction factor may vary over the pipe lifetime as scaling or pitting develops.

Pipe diameter changes are relatively inexpensive. Usually excavation, backfill, and installation costs do not increase proportionately to pipe diameter and the total installed pipeline costs for larger pipe can produce significant pumping cost savings.

The pipeline size and material should be selected to minimize the total system cost including both initial capital costs and annual operating expenses. This can be done by viewing total costs in terms of initial and annual costs and discounted present worth. The relationship between pumping energy costs and pipeline cost is illustrated in the figure. The optimum pipeline size for the system occurs when total system costs are minimized. Other factors such as future expansion, fluid velocities under certain demand conditions, etc., may modify the optimum size. The exercise, however, does indicate the most economical size given certain parameters, and should serve as a guide.



PIPE SIZE OPTIMIZATION

SYSTEM EVALUATION

In the previous sections, several options and considerations for a pipeline system were discussed. These represent a few of the considerations to be evaluated in a design. Socioeconomic and environmental concerns should also be included in an overall system evaluation.

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