WELL PUMPS AND PIPING

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Well pumps for larger geothermal applications are normally of the lineshaft, vertical turbine type with the electric motor located on the surface. This type of pump with oil lubrication and adequate allowance for thermal expansion has proven to be a reliable design. Unfortunately, it is not an economical selection for small residential and commercial applications. In fact, there really is no completely satisfactory solution to small flow rate, hot water well pumping applications. The two most commonly used options are conventional electric submersible pumps and jet pumps.

SUBMERSIBLE PUMPS

In the case of conventional submersibles, most manufacturers warrantee their submersible motors for continuous operation in water equal to or less than 86°F. To operate standard motors in water temperatures in excess of this value, a combination of strategies can be used. This involves assuring a minimum flow rate past the motor for cooling and possibly increasing the motor size. A major manufacturer (Franklin, 1999) of submersible motors recommends the following procedure:

> "A minimum water velocity past the motor of 3 ft/sec is required for applications in which the water temperature exceeds 86°F. For small applications, using a nominal 4" submersible motor, this would require a minimum flow rate of 15 gpm and the use of nominal 4" well casing or a 4" ID flow inducer sleeve. The sleeve is a sheet metal shroud that fits over the motor and forces the water to flow past the motor before entering the pump intake. Flow inducer sleeves are available from the motor manufacturer as an accessory."

In addition to assuring the minimum flow velocity past the motor is achieved, it may also be necessary, depending upon the water temperature, to increase the size of the motor as well. This is only necessary at water temperatures greater than 122°F for small motors (<5 hp), and water temperatures greater than 113°F for medium size motors (7.5 to 30 hps). Table 1 provides "Temperature Correction Factors" for submersible motors. The values in the table assume that other measures have been taken to assure a minimum velocity of 3 ft/sec past the motor as discussed above.

The required brake horsepower from the pump manufacturers curve is multiplied by the "Temperature Correction Factors" from Table 1. The resulting "corrected horsepower" is then used to select a motor with a "Service Factor Horsepower" of equal or greater value from Table 2.

Table 1. Temperature Correction Factor (Franklin, 1999)

Max. Water Temp.	<5 HP	7.5 to 30 HP
140	1.25	1.62
131	1.11	1.32
122	1.00	1.14
113 and below	1.00	1.00

Table 2. Service Factor Horsepower (Franklin, 1999)

Nominal HP	Service Factor HP
1/3	0.58
½	0.80
3/4	1.12
1	1.40
1 ½	1.95
2	2.50
3	3.45
5	5.75
7 ½	8.65
10	11.50
15	17.25
20	23.00

Example: Select a motor for an application in which the water temperature is 137°F and a break horsepower requirement of 2.1 hp. In a normal cold-water application, we might choose a nominal 2-hp motor for this duty. Based on the water temperature, however, a "Temperature Correction Factor" of 1.25 is selected from Table 1. Multiplying the correction factor by the required BHP results in a corrected horsepower of 2.63 hp. From Table 2, we would select a nominal 3-hp motor for this application. Since it is the smallest motor with a service factor horsepower higher than the 2.63 required.

This procedure can be used for applications up to a temperature of 140°F. As an alternative, or for water temperatures up to 167°F, a motor specifically designed for operation at higher water temperatures must be used. These motors are available from at least one manufacturer in sizes of 2 through 10 hp in 3-phase and 2-, 3- and 5-hp single phase. No special shrouding or sizing considerations apply. Since these motors are designed for oil field duty and are low-production products, a significant cost premium applies.

JET PUMPS

An alternative to submersible pumps is the jet pump. This is a type of well pump in which both the pump and electric motor are located aboveground and thus, special consideration related to submersible motors are eliminated. This type of pump recirculates a flow of water between the surface and a "jet" located below the water surface in the well. The configuration of the "jet" (more accurately a venturi) causes the recirculating water to draw in water from the well and deliver it to the surface. These pumps are less efficient than submersible pumps and for a given horsepower may produce only 20 to 30% of the flow as submersibles. Based on data available in the Geo-Heat Center, most jet pump systems have a maximum allowable water temperature of 140°F; though, we are aware of systems in which they have been successful at temperatures up to 180°F. These temperatures appear to be more related to the pump than to the downhole components (piping and jet). Jet pumps are limited to 1-1/2 hp and flow rates of approximately 10 gpm at a depth to water of 50 ft.

PRESSURE TANKS

Pressure tanks can be used to deliver hot water to a small heating system just as they are used for delivering cold water to the home. Older, air cushion-type tanks, in which the air is directly exposed to the geothermal water are not recommended. This type of tank allows the water to absorb oxygen from the air and greatly accelerates the corrosion of any iron and/or steel components downstream. Pressure tanks used for hot water applications should be of the "diaphragm" type. Most tanks equipped with a butyl rubber diaphragm have a maximum water temperature rating of 160°F. Some larger tanks are rated for as high as 200°F water. Be sure to verify that the tank you are using is rated for operation at a water temperature equal to or greater than the well water temperature.

PIPING

Pipe Sizing

The size of pipe necessary for a particular flow rate is determined by the pressure drop which is considered acceptable by the designer. Some general guidelines have been developed in the past for this purpose. Basically, the decision is based upon a balance between the pumping costs over the life of the line (to overcome the pressure loss) compared to the first cost of the pipe. Larger pipe costs more to buy, but results in lower pressure drop (and pumping cost) for a given flow rate. Based on maximum pressure loss rate of 4 ft per 100 ft of pipe recommended by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) in their energy consumption standard 90, the following maximum flow rates for various pipe sizes would apply:

Table 3. Recommended Maximum Flow Rates

Nominal Pipe Size (inches)	Maximum Flow Rate (gpm)
½	2
3/4	4
1	8
1 1/4	12
1 ½	22
2	40
2 ½	70
3	120
4	260
6	550

Plastic Pipe for Hot Water Applications

Both steel and copper pipe should be used with caution in direct-buried installations carrying geothermal water. Steel pipe is susceptible to both interior (from the geothermal water) and external (from soil moisture) corrosion. Of these, past experience has proven that the exterior corrosion is by far the most serious. Uninsulated steel pipe carrying hot water appears to have a useful service life of approximately 7 to 10 years. Copper pipe suffers less from exterior corrosion than steel, but is more susceptible to interior corrosion from the geothermal fluid. Most geothermal fluids contain some hydrogen sulphide, the compound that gives the water a rotten egg smell. Hydrogen sulphide is very aggressive toward copper. In addition, some geothermal fluids can rapidly (3 to 4 years) deteriorate the solder used to join the copper pipe. For these reasons, these otherwise standard materials have seen little use in geothermal applications, unless a heat exchanger is used to isolate the geothermal fluid.

Piping, to deliver hot water from the well to the pressure tank or to the point of use, can be of a variety of materials. Plastic materials are often used to eliminate the danger of corrosion, both internal and external. The most commonly available plastic piping materials are PVC and CPVC. In both cases, it is necessary to evaluate the suitability of the pipe in terms of both temperature and pressure. Thermoplastic piping is characterized by a diminished ability to handle pressure at elevated temperatures. PVC pipe has a maximum service water temperature of 140°F and CPVC a maximum service temperature of 180°F. In both cases, the pressure rating of the pipe is greatly reduced at these temperatures. Table 4 provides pressure rating adjustment factors for PVC and CPVC piping at various water temperatures.

Table 4. PVC and CPVC Pressure Rating Correction Factors (NIBCO, undated)

Temperature	PVC	CPVC
70	1.0	1.0
80	0.9	0.96
90	0.75	0.92
100	0.52	0.85
110	0.50	0.77
120	0.40	0.70
130	0.30	0.62
140	0.22	0.55
150	NR	0.47
160	NR	0.40
170	NR	0.32
180	NR	0.25

Table 5. Maximum Operating Pressure in PSI (NIBCO, undated)

Nominal Size	
½	600
3/4	480
1	450
1 1/4	370
1 ½	330
2	280
2 ½	300
3	260
4	220
6	180

Example: Calculate the maximum operating pressure for 2-in. PVC pipe at a temperature of 130°F.

Table 5 presents pressure ratings for both PVC and CPVC pipe at 73°F. To arrive at the maximum operating pressure for any other temperature, multiply the temperature correction factor from Table 4 times the 73°F pressure rating in Table 5.

From Table 5, the pressure rating at 73°F is 280 psi. At 130°F, a de-rating factor of 0.30 applies. This results in a maximum operating pressure for this application of 0.30 x 280 = 84 psi.

The question of heat loss from buried piping is a frequent concern of small system owners. Whether or not the piping will lose enough heat to significantly reduce the temperature of the water at the other end of the line is worth some evaluation. Heat Loss from buried piping is influenced by the soil thermal conductivity, pipe material, water temperature and burial depth among other parameters. Figure 1 presents heat loss information for plastic (PVC and CPVC) pipe at a 3-ft burial depth for two different soil types and three different pipe sizes. The highest heat losses are experienced

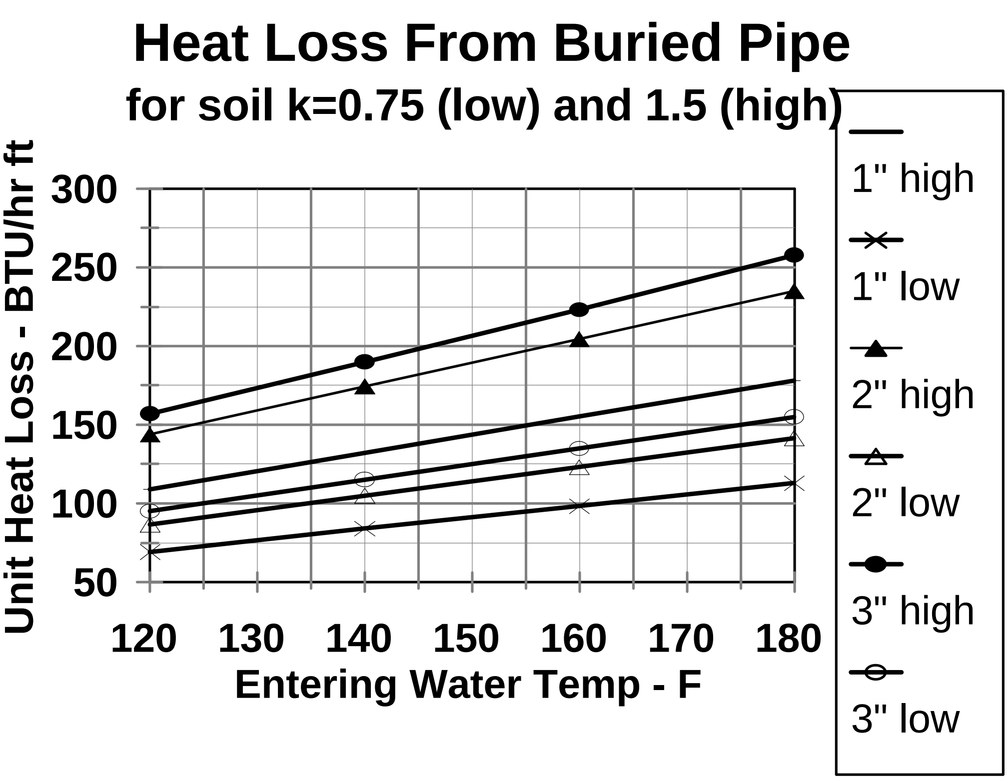

Figure 1. Heat loss from buried pipe (soil k - 0.75 (low) and 1.5 (high)).

in heavy damp soil, indicated as "high" (1.5 Btu/hr·ft) in the figure. Dry, light soil indicated as "low" (0.75 Btu/hr·ft) in the figure retards heat losses. Most soils will fall somewhere between these two. The descriptors high and low refer to the thermal conductivity (Figure 1) of the soil usually expressed in Btu/hr·ft°F. The figure provides heat loss in Btu/hr per linear ft. In order to determine the temperature loss in a line, it is necessary to know the length and the quantity of water flowing (gpm) in the line. The greater the flow rate, the lower the temperature change for a given situation.

Example: Calculate the heat loss and temperature drop for a 2-in. line, 250 ft long which is carrying 10 gpm of 150°F water. Assume worst case conditions for the soil.

From Figure 1, the heat loss per foot is approximately 1750 Btu/hr per linear foot using the curve for high heat loss (high soil thermal conductivity). The total heat loss for the line would be 175 Btu/hr x 250 ft = 43,750 Btu/hr.

The temperature drop in the line can be calculated by dividing the total heat loss by 500 x gpm; where, the gpm is the flow in the line, in this case 10 gpm. As a result, the temperature loss would be: 43,750 Btu/hr/(500 x 10) = 8.75°F.

For lines of a few hundred feet in length, the temperature loss is almost directly proportional to the water flow. For the above example, the temperature drop at 20 gpm would be approximately 4.4°F and at 2 gpm would be approximately 44°F. As a result, one method of controlling the temperature loss in a line is to maintain a flow that results in an acceptable temperature at the end of the line.

The above examples and discussion are based on what is referred to as the "steady-state" heat loss from a buried pipe line. This means that the line has been carrying the flow of hot water long enough that the surrounding soil has been heated up to an "equilibrium" condition. At initial start up, the temperature loss would be much greater than the values indicated since a great deal of heat would be required to raise all the soil around the line from it's undisturbed temperature to a value closer to the pipe temperature. This issue can also have implications as far as the way the line is operated. If a line is to carry only intermittent flow or if it is to carry widely varying flow, it is important to make the heat loss and temperature drop calculations at the worst case condition. For intermittent flow applications, it is sometimes useful to maintain a small, constant flow to stabilize the line temperature and avoid wide temperature fluctuations.

The obvious way to minimize heat loss from a buried line is to insulate the pipe or at least increase the thermal resistance between the pipe wall and the soil. Several methods are available to accomplish this task. The most common is pipe insulation of some type. In larger applications with long pipelines, pre-insulated pipe is often employed. This is a product that consists of a carrier pipe (through which the water flows), a layer of urethane foam insulation and a jacket to protect the insulation from soil moisture. The cost of pre-insulated pipe in the two inch size is on the order of $10 per foot higher than bare pipe material in the same size. As a result, small project developers are often interested in identifying other options to reduce heat loss from buried lines. One of the least costly approaches is to bed the pipe in a dry,

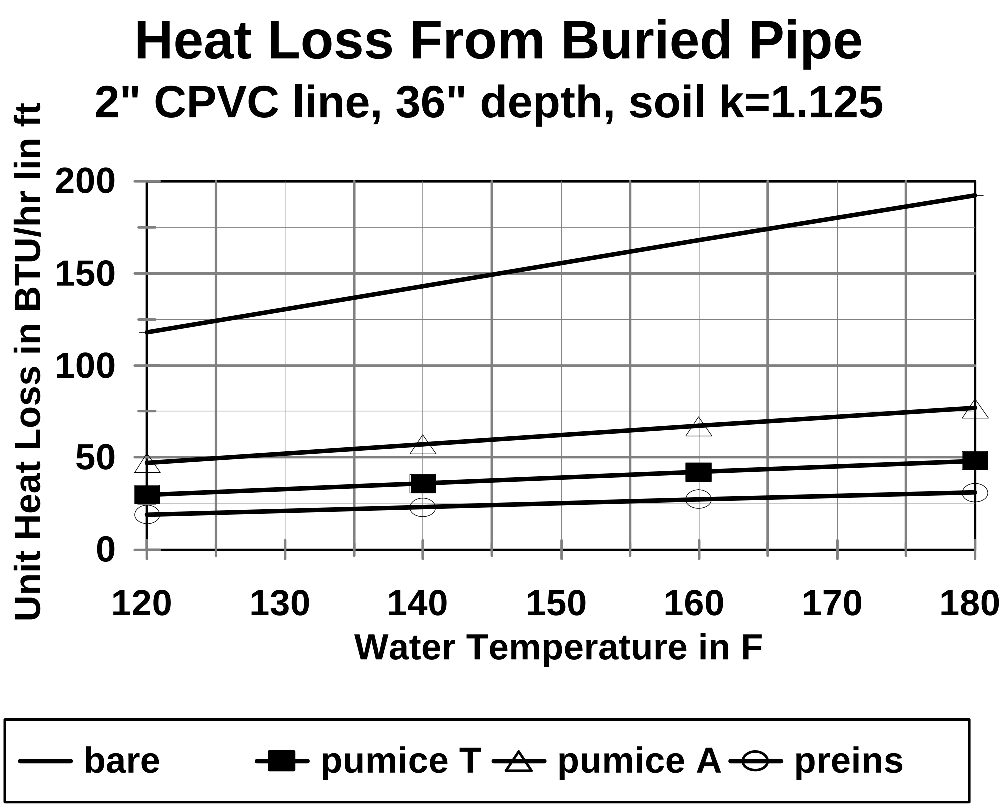

Figure 2. Heat los from buried pipe (2-in. CPVC line, 36 in. depth, soil k =1.125).

low thermal conductivity material that readily drains away any water from the pipe. A common material fitting this description is pumice. The thermal conductivity of dry pumice is approximately 0.085 Btu/hr·ft·°F or about 10% that of most soils. This value is approximately 3 to 4 times that of commonly used pipe insulation materials.

The pumice is installed in the pipe zone in such a way that the pipe is surrounded by several inches of pumice on all sides. Figure 2 indicates the effectiveness of the pumice approach relative to an uninsulated line, and a pre-insulated line with 1inch of polyurethane insulation. In theory, the pumice (pumice T) will approach the performance of the pre-insulated line. In actual installations, however, experience has shown that the conductivity of the pumice is degraded by moisture in the soil. The actual performance of pumice is reflected in the curve labeled "pumice A." This constitutes approximately a 60% reduction in heat loss compared to the uninsulated line using a 6-in. thick layer of pumice around the line. At $10 per yard for the pumice and using a trench 12 in. wide, sheeting should be placed over the top of the pumice to protect it from vertical percolation of water in the soil. To prevent soil invasion of the pumice (which would raise its conductivity), a filter cloth can be used to line the ditch.

The black polyethylene pipe insulation available in tubular form at many home improvement stores is not intended for below grade installation. Though it is suitable for use in pipe temperatures up to 180°F in many cases, it's performance under buried conditions is not known. Under no circumstances should it be installed on steel pipe in direct-buried applications. This type of insulation can trap moisture next to the pipe and greatly increase exterior corrosion.

HEAT EXCHANGERS IN GEOTHERMAL SYSTEMS

In large geothermal direct-use systems, it is common practice to isolate the geothermal water from the balance of the system using a heat exchanger. The geothermal water passes through one side of the heat exchanger and the heating system water the other side. Thin stainless steel plates separate the two water flows so that there is no actual contact or mixing. Only heat passes through the plates from the geothermal water to the "clean" water. The use of the heat exchanger eliminates the potential for corrosion or scaling in the heating equipment in the building. In large applications where there may be tens of hundreds of individual heating units, the cost of the heat exchanger relative to the value of the equipment it protects is favorable. For very small systems, such as those addressed in this document, it is normally more economical to use the geothermal water directly in the heating equipment and accept a shorter service life for the heating units.

An exception to this is in the heating of domestic hot water. A small version of the plate heat exchanger called a brazed-plate heat exchanger (BPHX) serves well in this application. It's performance does not reach the level of the larger plate exchangers and it cannot be disassemble to be cleaned, but it is cost effective for small domestic water heating applications. Rather than being held together with the heavy end plates, large bolts and gaskets of plate-and-frame heat exchangers, the heat transfer plates in BPHXs, as the name implies, are brazed together with copper. The copper is subject to attack by hydrogen sulphide in the geothermal water, but testing has demonstrated (Rafferty, 1990) that service lives of 7 to 12 years in most geothermal fluids can be expected. These are the type of heat exchangers recommended in the domestic hot water heating portion of this document.

REFERENCES

Franklin Electric, 1999. Applications - All Motors / website: http://www.franklinelect.com/manual/g.htm. Franklin Electric, Bluffton, IN.

NIBCO, undated Chemtrol Plastic Piping Handbook, NIBCO, Inc., Elkhart, IN.

Rafferty, K., 1990. "Brazed-Plate Heat Exchangers for Geothermal Applications." Geo-Heat Center, Klamath Falls, OR.