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Flooded Underground Coal Mines:

A Significant Source of Inexpensive Geothermal Energy

Introduction

Many mining regions in the United States contain extensive areas of flooded underground mines. The water within these mines represents a significant and widespread opportunity for extracting low-grade, geothermal energy. Based on current energy prices, geothermal heat pump systems using mine water could reduce the annual costs for heating to over 70 percent compared to conventional heating methods (natural gas or heating oil). These same systems could reduce annual cooling costs by up to 50 percent over standard air conditioning in many areas of the country.

Background

Lord Kelvin first developed the concept of heat pumps in 1852 (Lund et al. 2004). In the 1940s, Robert Webber modified the concept by using the ground as the source of heat (Lund et al. 2004; IGSHPA 2005). These ground source or geothermal heat pump systems gained popularity in the 1960s and 1970s due to oil shortages, and many alternative types of energy systems were developed (Bloomquist 1999). Today, 500,000 geothermal units are used for residential heating and cooling in the United States and Canada with an additional 400,000 units in Europe (Manitoba Budget Papers 2004). Geothermal heat pumps are one of the fastest growing types of renewable energy in the world, with annual increases of 10 percent in approximately 30 countries in the last 10 years (Lund 2001). Right now, interest is very high due to the high prices of natural gas, heating oil and propane. The cost effectiveness of geothermal heat pump systems is directly related to the ratio of the cost of conventional heating fuels (such as natural gas, heating oil and propane) to the cost of electricity (needed to drive the heat pump). Currently, this ratio is the highest it has ever been.

A heat pump moves heat from one place to another. It can be used for either heating, by moving heat into an area, or cooling, by moving heat out of an area. A re-

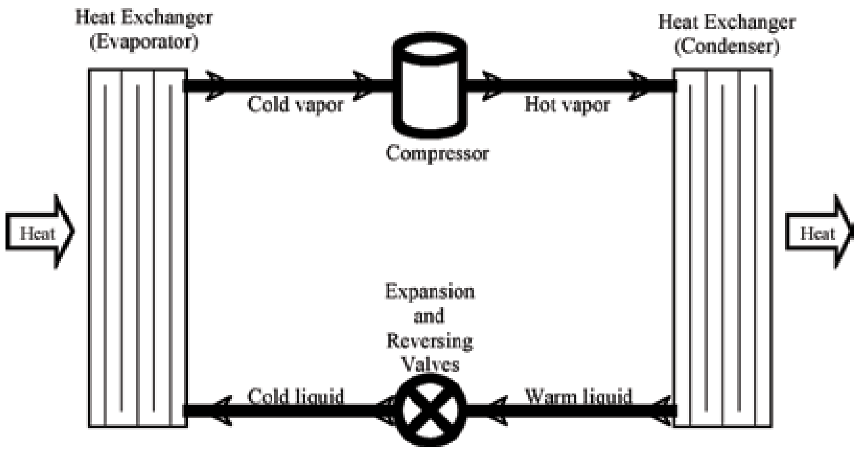

Figure 1. Schematic of a heat pump system in heating mode. Heat source is in contact with the evaporator.

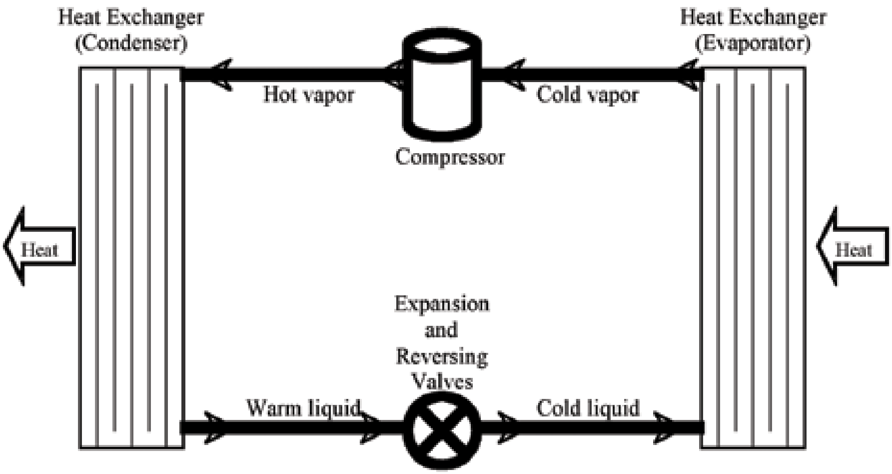

Figure 2. Schematic of a heat pump system in cooling mode. Heat sink is in contact with the condenser.

frigerator is an example of a heat pump. It moves heat from inside the box to outside the box. Within the heat pump, a refrigerant is used that absorbs heat when going through a phase change from a liquid to a vapor. A compressor is used to compress this vapor, thereby increasing its temperature. Then, an expansion valve allows for the vapor to be converted back to a liquid. Figure 1 shows a diagram of a heat pump system. A heat pump is made up of two heat exchangers, a compressor, an expansion valve and a reversing valve. In heating mode, the refrigerant – in a cold liquid form – gains heat from the outside source (air or ground) in a heat exchanger (evaporator), where it is converted into a cold vapor. After the liquid absorbs heat and is converted to a vapor, it is then compressed (requiring an input of electrical energy), converting it to a hot vapor. The hot vapor is sent to another heat exchanger (condenser). Here, the hot vapor gives up the heat that was gained from the source in the evaporator and, in the process, is condensed to a hot liquid (the heat given up is used to heat the interior space). The hot liquid goes through an expansion valve where the drop in pressure converts it to a cold liquid and the process is repeated. In heating mode, the evaporator is placed in contact with the heat source. In cooling mode, the above process is reversed with the use of a reversing valve (Figure 2).

Ground source or geothermal heat pumps use the near-constant temperature of the earth (in soil/rock, groundwater or deep surface waters). During winter months, the earth is at a higher temperature than the outside air and, therefore, acts as a heat source. In summer, the earth is at a lower temperature than the outside air and, therefore, can act as a heat sink. Because of this, geothermal heat pump systems are much more efficient than air source systems for both heating and cooling. For heating, the amount of heat generated divided by the amount of energy needed to operate the heat pump is known as the coefficient of performance (COP). A typical COP value for an air source heat pump is about 2, while geothermal systems have COP values commonly between 3 and 4, with values as high as 6 reported in the literature (Sound Geothermal Corporation 2003; O'Connell and Cassidy 2003). Geothermal heat pumps typically use about half the energy needed for cooling with air source systems.

A ground source heat pump can be designed in a variety of styles based on groundwater access, land availability and drilling costs. The two main categories of ground source heat pumps are closed loop and open loop systems (U.S. DOE 2001). In a closed loop system, no fluid is extracted or discharged to the environment. Pipes, which are filled with an antifreeze solution, are buried in the ground in either a horizontal or vertical format. The antifreeze solution is pumped through these pipes exchanging heat with the ground. An average-sized house in the northeastern United States may require over 1,500 linear feet of pipe. The horizontal format requires a significant amount of area to bury the pipes. If there is not sufficient area for use of the horizontal piping, a vertical system must be used. In the vertical format, 100- to 400-foot deep boreholes must be drilled and pipes are placed in a U-shape within the boreholes. An average home may require two to eight boreholes. The cost of installing the closed loop piping system is the most significant cost of the geothermal system and can exceed $10,000 for an average-sized home. An open loop system eliminates the expense of loop installation. In the open loop system, groundwater or deep surface water is extracted from the environment and subsequently discharged back into the environment. The typical flow rate for an open loop system is about 1 to 3 gallons per minute per ton (1 to 3 liters per minute per kilowatt-hour) of heating and cooling (PADEP 2001) (One ton of heating and cooling is equivalent to 12,000

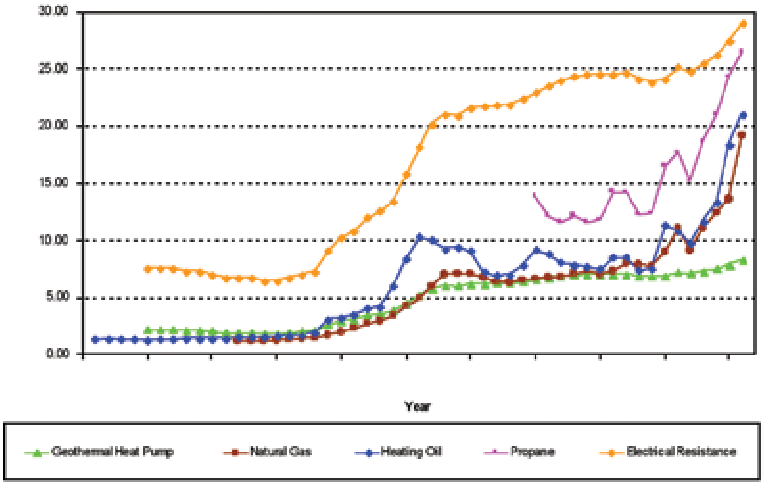

Figure 3. Costs for using these typical heating systems based on average U.S. energy prices from 1990 to 2006. Furnaces using propane, natural gas or fuel oil, were assumed to be moderately efficient (84 percent). Coefficient of performance (COP) of geothermal heat pump was assumed to be 3.5.

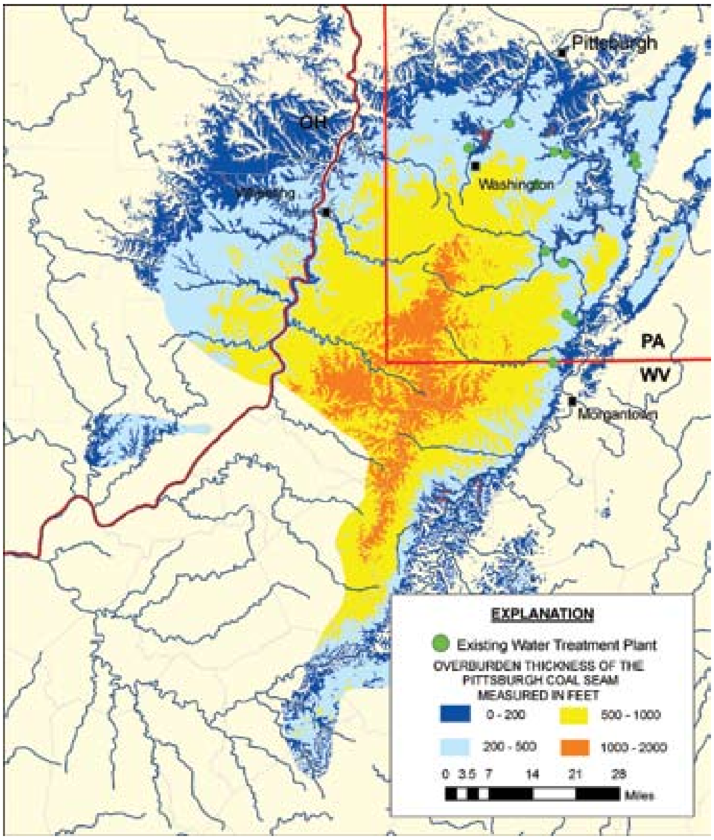

Figure 4. Overburden depths above the Pittsburgh coal seam in Pennsylvania, West Virginia and Ohio and location of existing water treatment facilities in Pennsylvania.

British thermal units per hour). If the quality of the water is such that it could cause scaling or corrosion within the heat pump, an additional heat exchanger filled with antifreeze solution may be used.

Cost Effectiveness of Geothermal Heat Pump Systems

The cost effectiveness of geothermal heat pump systems for heating is directly related to the cost of electricity (to operate the heat pump) compared to the cost of the other conventional fuels: natural gas, heating oil and propane. Figure 3 shows the costs over the past 50 years for electricity, natural gas, heating oil, propane, as well as the cost for the electricity required for a geothermal heat pump system. To get a true representation of the actual cost to the consumer, the efficiencies of each system utilizing the fuel/energy source must be taken into account. In Figure 3, an assumed 84 percent efficiency is used for furnaces/boilers burning natural gas, heating oil or propane, and a relatively conservative COP of 3.5 is used for a geothermal heat pump (Sound Geothermal Corporation 2003).

Use of Mine Water in Geothermal Heat Pumps

There have been a few examples of the successful use of mine water in geothermal heat pump systems. Systems using water from abandoned mines have been installed in Canada (Jessop et al. 1995), the United States (GHPC 1997) and the United Kingdom (John Gilbert Architects; John Gilbert Architects 2002).

Potential of the Pittsburgh Coal Seam Mine Pool for Heating and Cooling

A significant volume of the Pittsburgh coal seam in Pennsylvania, West Virginia and Ohio is currently flooded. As shown in Figure 4, the availability of underground mine water in the Appalachian coal region is very widespread. Approximately 5,000 square miles (13,000 km^2) have been mined in the northern portion

Table 1. Energy costs for use of typical heating systems in southwestern Pennsylvania.

Energy source	Formula for cost per 10^6 Btu	US$/$10^6$ Btu*
Propane	(11.1 x cost/gallon) / efficiency	32.11
Electrical Resistance	293 x cost/kWh	20.80
Fuel Oil	(7.25 x cost/gallon) / efficiency	20.28
Natural Gas	(970 x cost/cubic feet) / efficiency	20.81
Geothermal Heat Pump (COP = 3.0)	(293 x cost/kWh) / COP	6.93
Geothermal Heat Pump (COP = 3.5)	(293 x cost/kWh) / COP	5.94
Geothermal Heat Pump (COP = 4.0)	(293 x cost/kWh) / COP	5.20
Geothermal Heat Pump (COP = 6.0)	(293 x cost/kWh) / COP	3.47

*Cost of fuels and electricity were based on actual delivered cost to the Pittsburgh, Pennsylvania area during the winter of 2006. Propane = $2.43/gallon, electricity = $0.071/kWh, fuel oil = $2.35/gallon, and natural gas = $0.01802/cubic feet. Furnaces using propane, natural gas or fuel oil were assumed to be moderately efficient (84 percent). Most geothermal heat pumps operate at a coefficient of performance (COP) between 3.0 and 4.0 with values as high as 6.0 reported in the literature. In addition to the electricity cost to operate the geothermal heat pump, there would be a cost to pump the water to the system. To pump the water from a discharge to the system from depths of 100, 250, 500 and 1000 feet would add an estimated $0.46, $0.92, $1.69 and $3.23 per million Btu, respectively.

of the Appalachian coal fields and nearly 2,000 square miles (5,000 km^2) are currently flooded (Donovan et al. 2004). The heating and cooling capacity of this underground mine water is an extremely valuable resource that is not currently being utilized. Throughout the Pittsburgh coal basin region, the water is easily accessible and maintains a constant temperature of 50 F to 55 F (10 C to 13 C) (USDOE 2001). The total volume of water estimated to be stored in the Pittsburgh coal seam is 1.36 x 10^{12} gallons (5.15 x 10^{12} liters) (Donovan et al. 2004). About 4 percent of this volume is discharged at the surface each year by treatment plants and abandoned discharges, which total about 5.3 x 10^{10} gallons per year (Donovan et al. 2004). This current amount of discharged water could potentially be used to heat and cool up to 40 million square feet (3.74 million m^2) of interior space, roughly equivalent to 20,000 homes. As the mines in this area continue to fill with water and with new voids being created by active mining, the volume of stored and discharged water from these underground mines will continue to increase into the future.

Table 1 shows the cost for generating 1 million Btu of heat for geothermal heat pump systems compared to conventional heating technology using actual energy costs in the southwestern Pennsylvania area. Electricity and natural gas costs were calculated using the actual residential utility bills in southwestern Pennsylvania by dividing the total cost (including distribution, taxes and other incidental charges) by the amount of the commodity received (kilowatt-hour for electricity or cubic feet for natural gas). Heating oil and propane prices were based on actual delivered cost to a consumer in the area, again dividing the total cost by the volume received.

Because mining companies are required to treat mine water, it has always been considered a liability. If the technology of using mine water in geothermal heat pump systems proceeds, clarifications of legal rights for mine water may need to be addressed. Given the geothermal potential of mine water, non-mining entities may be enticed to use mine pool water for heating and cooling capabilities. If mine water were brought to the surface, the water would be either returned directly back into the mine pool or treated and discharged at the surface.

Summary and Conclusions

Use of underground mine water in geothermal heat pumps could be extremely cost effective, particularly at existing mine water treatment sites where the mine water is already being pumped and treated. Operational costs for geothermal heat pumps are much lower than that of conventional heating and cooling options. Costs per unit of heat for geothermal heat pumps (COP=3.5) using underground mine water are only 29 percent, 29 percent, and 18 percent of the costs incurred using fuel oil, natural gas or propane, respectively. Cooling costs using mine water and geothermal heat pumps should be less than 50 percent of the costs associated with conventional air conditioning systems.

The availability of mine water in the Appalachian coal region is widespread. The heat content of the mine water is a valuable resource that is not currently being utilized and is simply being discharged with the treated mine water to a receiving stream. The amount of water that is currently being discharged from underground coal mines in just the Pittsburgh coal seam, could potentially be used to heat and cool up to 40 million square feet of interior space, roughly equivalent to 20,000 homes. Using the additional water stored in the mines could conservatively extend this option to an order of a magnitude of more homes. Because most mines are currently filling, the volumes of discharged and stored water will continue to increase in the future. Research is needed to demonstrate and develop this extremely valuable resource.

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