USING MINE WATERS FOR HEATING AND COOLING

Schubert, J.P., and McDaniel, M.J.

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439. U.S.A.

ABSTRACT

In northeastern Pennsylvania, two heat pump systems are now operational and another is being constructed. These systems use waters pumped from flooded underground anthracite mines to heat and cool buildings. During winter, mine water is pumped out at about 15°C, circulated through a heat pump system, and returned at about 11.5°C to the underground mines. Energy derived from the mine waters is more than adequate to heat the buildings with no need for conventional oil or gas boiler systems. Cooling during the summer is accomplished with the mine water heat pump systems, also at a great cost savings. These systems could be used with discharges from active mines, resulting in savings to the mining companies of 25-60% of what is spent on conventional heating and cooling.

INTRODUCTION

The term "heat pump" refers to refrigeration systems which can produce heating or cooling. The purpose of a heat pump system is to transfer heat from one fluid where it is unwanted to another fluid where it is wanted. The fluids involved are usually air, water, and refrigerant. An example of a heat pump is an air conditioner in a building; heat is transferred from the air in the building to a fluorocarbon refrigerant in a closed loop within the air conditioner, and then to the outside air. Unwanted heat in the building air is transferred to the outside air; thus, an example of an air-to-air heat pump. If the cycle were reversed and the heat pump put in a heating mode, then heat from the outside air would be transferred to the inside. The basic refrigeration system is the same whether heating or cooling is the desired end product.

Because water has a much higher specific heat capacity /4.18 $J \cdot g^{-1} \cdot K^{-1}$/ than air /~1.00 $J \cdot g^{-1} \cdot K^{-1}$/, it is much more efficient as a heat source or sink in a heat pump system. Using groundwater for a heat pump system is not a new idea, but one that is rapidly gaining popularity in the United States and northern Europe. Groundwater heat pump systems have been in operation for as long as thirty years now and, in most cases, considerable energy savings have resulted from the heat pump systems as compared to all other forms of interior space temperature control.

Groundwater has certain thermal properties that make it an excellent potential energy source or sink for heat pumps: /1/ groundwater is generally abundant everywhere, /2/ the temperature of shallow groundwater normally ranges between 5 to 24°C in temperate climates, /3/ unlike air or surface water, the seasonal variation of groundwater temperature is small, and /4/ the specific heat capacity of water is relatively great /meaning that large amounts of energy can be extracted for heating for a small reduction in water temperature/. Groundwater is always warmer than the overlying mean daily air temperature in winter and cooler than air in summer. As a result, a groundwater source heat pump can extract energy from the water to heat air in winter /heating mode/ and expel heat to the groundwater during summer /cooling mode/.

GROUNDWATER HEAT PUMP ENGINEERING

The basic groundwater heat pump system consists of seven major components: /1/ the compressor, /2/ a water/refrigerant heat exchanger, /3/ a refrigerant/air heat exchanger, /4/ a refrigerant expansion device /often a capillary tube/, /5/ the refrigerant, /6/ a reversing valve, and /7/ an air blower. These components are shown in Figure 1 for the heating mode. Hot refrigerant gas is pumped from the compressor to a refrigerant/air heat exchange coil. Air is blown across the exchanger and removes heat from the hot gas, which condenses to a liquid. The refrigerant then flows through a capillary tube or other expansion device causing a reduction in pressure. When the refrigerant passes through the water/refrigerant heat exchanger, it absorbs heat from the water and becomes a gas. It then flows through the reversing valve and back to the compressor.

During the cooling cycle in summer, air flow and water flow through the exchangers remain exactly the same, but the refrigerant flow is reversed by the reversing valve /Figure 2/. In this case, the hot refrigerant gas flows through the water heat exchanger, condenses, and gives up heat to the circulating groundwater. The cooled refrigerant liquid evaporates in the air side coil by absorbing heat and cooling air that passes over the coil.

The refrigerant/air heat exchanger usually consists of copper tubes and very thin aluminum fins /~4-6 fins per cm of tubing/. The water/refrigerant heat exchanger is typically a coaxial /tube inside a tube/ coiled unit. The groundwater flows through the inner tube, which should be made of cupro-nickel metal. The refrigerant flows in the opposite direction through the annular space between the outer tube and inner tube [1]. Some other types of liquid/liquid heat exchangers consist of a coiled tubing within a water jacket shell, or thin alternating metal plates.

The greatest attribute of the groundwater heat pump system is the fact that it produces more heat than the equivalent of its electricity consumption:

$$E_t = \Delta E_g + E_e, \qquad /1/$$

where E_t = total thermal energy produced, ΔE_g = thermal energy removed from groundwater, and E_e = electrical energy /converted to thermal energy equivalent/ consumed by a heat pump. The ratio of thermal energy output to electrical energy imput is the measure of the unit's efficiency, or Coefficient of Performance /COP/:

$$COP = E_t/E_e \qquad /2/$$

For many groundwater heat pump systems currently operating in the United States, the COP usually ranges between 2.8 to 3.5, and has been reported as high as 5.0 for some units [2]. By extracting the free thermal energy from groundwater, the heat pump system utilizes considerably less electrical or fossil fuel energy than conventional air conditioning or heating units. Thus, a heat pump system could reduce he fuel costs of heating or cooling a building by 25 to 50% or more.

USING MINE WATER

Almost every underground mine, regardless of the mineral/s/ being exracted, usually encounters some amount of groundwater inflow. This mount can either be very small or several thousand liters/second. As normal part of any mining operation, water is collected in sumps and umped to the surface, sometimes treated, and eventually discharged. he amount of thermal energy being discarded is usually very signifiant. If this thermal energy were recovered using a heat pump system, hen great cost savings could be realized by mining companies for eating nearby buildings. As an example, assume a mine pumps out 20 /s of water having a temperature of 16°C. If a heat pump system exracts enough thermal energy from the mine water to reduce its temperture by 5°C, then 418,000 Joules of thermal energy could theoreticlly be recovered every second /3.6 x 10^{10} J per day/. This amount is ufficient to heat about 24 medium-sized houses.

he great advantage of this system is that the groundwater from the ine must be pumped out, so the pumping system is already in place /no dditional expenditures need to be made/. If the mine has a horizonal /drift/ entrance and mine water flows out by gravity, then the umping system for the heat pump water supply may not be needed at ll. For an active mine, the only costs involved would be /1/ instalation and maintenance of the heat pump system, and /2/ cost of electricity to operate the heat pump compressor.

nother very important potential source of mine water for heat pumps s stored in abandoned underground mines /Figure 3/. There are probbly over 10^6 of these flooded mines around the world. If they happen o be located under a populated area and the depth or difficulty of rilling is not excessive, then there is a vast storehouse of water hat could provide heating or cooling at a relatively cheap cost. ftentimes, geological materials underlying an area are relatively mpermeable and will yield less than 1 L/s to a well. These small mounts of groundwater may be sufficient to heat a small house, but reater quantities are needed for larger buildings, housing developents, and industrial plants. Flooded underground mines are usually apable of yielding unlimited quantities of water to a properly placed ell. If a flooded mine drains out of the side of a hill by gravity, hen a heat pump system could be placed at that location and no well pump is needed at all /Figure 3C/.

Not only do underground mines have the capability of yielding greater amounts of water than the average well in a groundwater aquifer, but the temperatures of some mine waters are higher than shallow groundwater, making it a more attractive source for heating. Although uncommon, some mine waters can be very hot. Anderson [3] has reported waters entering some gold-silver mines in Nicaragua to be as hot as 77°C; water from one mine approached 76°C and pumping rate was about 190 L/s. If this mine were located in a colder climate, the mine water would be an excellent source of thermal energy for heating of buildings. Mine waters as low as 4.5°C are usable for a heat pump system. Mine waters are almost always greater than 4.5°C, so this factor would not be an impediment to heat pump utilization.

In summary, the best reasons for using mine water heat pump systems are that:

/1/ water is already being pumped out of active mines and sometimes drains out of abandoned, flooded mines by gravity; hence, pumping costs are low or nonexistent.
/2/ the quantity and temperature of mine waters are usually very favorable for heat pump operation.
/3/ buildings for mining and mineral processing are usually located adjacent to the mine mouth; therefore, the mine water could easily be piped to those nearby structures.
/4/ with rising costs of oil, gas, and coal, mining companies should take advantage of the opportunity to capture free thermal energy from mine waters.
/5/ like groundwater heat pumps, mine water heat pump systems could be used for cooling in summer, thus eliminating the need for a separate air conditioning system.

Design of mine water heat pump systems for active mines would probably include a surface discharge of mine water after use. The water could be treated, if necessary, and discharged to a river or lake, or be contained in a recharge pond away from the mine to prevent recirculation back into the workings.

For flooded abandoned mines, water could be pumped from and discharged to the same vein /Figure 3E/ or pumped from and discharged to separate veins if several exist /Figure 3B/. The water could also be pumped from the mine and discharged to the surface /Figure 3A/, if water quality is acceptable. If pumping water back into a abandoned mine is necessary, the most advantageous location would be away from the heat pump supply well. By separating the supply and discharge wells, the chances of recirculation of "cold" discharge water back to the supply well during the heating mode would be greatly reduced /Figure 3B/. In addition, the discharge well in winter could be converted into the supply well in summer and "cold" water used for cooling air in the buildings. The storage of "hot" and "cold" water in separate areas could be accomplished by reversing the flow of water at the beginning of each heating and cooling season /Figure 3D/.

POSSIBLE CONSTRAINTS ON MINE WATER USE

The first and foremost consideration for installation of a mine water heat pump system is the need for energy. Unless there is a need for heating or cooling in the close vicinity of a mine, there is no need to consider a heat pump system. Mine water cannot be transported very far to a user before the costs of pipe and insulation make it economically infeasible. The allowable distance for transport must be determined on a case-by-case basis, depending on the quantity and temperature of mine water, the estimated heat loss during transport, the cost of the system, and the potential savings in energy and money

A very important factor to consider is the quality of the mine water and the ability of a proposed heat pump system to withstand corrosion, scaling, and proliferation of iron-oxidizing bacteria inside the heat exchanger. The low pH /<5.0/ of many mine waters can cause corrosion problems in the heat exchange unit. The heat exchanger should be made of cupro-nickel, stainless steel, or other corrosion-resistent metal alloys. An alternative would be to neutralize the acidity with lime and raise the pH prior to passing the mine water through the heat exchanger. All piping carrying mine water to and from the heat exchanger could be polyvinyl chloride /PVC/ to withstand low pH.

Iron and other metals dissolved in mine waters could possibly precipitate in the piping or heat exchanger, causing encrustation of the pipes, constriction of flow, and reduction in efficiency of a heat exchanger. A groundwater heat pump designed and constructed by Dr. Carl Nielsen in Ohio utilizes shallow groundwater that contains above average concentration of dissolved iron. After 22 years of operation, only a small amount of oxidation on the inside of the heat exchange pipe was evident, despite the high iron content of the water [4]. However, some problems of encrustation of the discharge pipe with iron precipitate did occur [5]. Within the heat exchange coil the groundwater was under pressure, but as the water went through the discharge pipe, pressure was reduced and gradually approached atmospheric pressure. The reduction in pressure and release of dissolved carbon dioxide may have caused a rise in pH of water and increased the oxidation rate and precipitation of iron. By maintaining pressure throughout the system, problems of iron precipitation could possibly be avoided in most systems pumping iron-rich water.

Scaling inside the heat exchange coils by calcium and magnesium carbonates is also possible and could be a large problem. Use of cupro-nickel alloy for the exchange tubes carrying groundwater may resist scaling buildup because of its expansion and contraction during temperature changes; scale buildup is periodically sluffed off and discharged. Scaling in a large groundwater heat pump system at Battelle Memorial Institute in Columbus, Ohio was a problem when the system first began operation in 1958. By adding a polyphosphate compound to the groundwater at a rate of 1 mg/L, the problem was remedied [6].

Iron bacteria was also an initial problem in the Battelle system; small diameter tubes and orifices became fouled with bacterial growth. A chlorinator was installed which maintains a 0.35 mg/L chlorine residual and the problem did not reoccur [6]. Iron bacteria growth in a reinjection well could cause a nuisance by clogging a well screen. When discharging to an abandoned mine, however, no well screen is necessary /discharge is usually to an open cavity/.

A mine water heat pump system can be designed to handle almost any water quality or bacterial problem that could effect the system engineering. However, the costs of the system would rise and economic benefits would decrease. At some point, poor water quality could cause a system to be economically infeasible.

Poor quality can also cause environmental and regulatory problems. Most mine waters in the United States must have a pH between 6.0 and 9.0 before being discharged from an active mine. For acid waters, this means addition of lime to raise the pH and use of settling ponds to separate precipitated iron oxyhydroxide before water is discharged to streams or lakes. Residents, firms, or other organizations that use mine water must also treat it, if acidic, before discharge to surface streams. If the water is to be pumped to the surface, heat extracted, and pumped back down to the flooded mine, the law is not clear as to requirements regarding quality control. Future regulations under the Federal Underground Injection Control Program and similar state regulations may dictate treatment of mine water before return to underground pools. This prospect is unlikely because use of mine water in a heat pump system should not alter the original quality of the water. If expensive treatment systems were required for either engineering reasons or discharge regulatory requirements, it is doubtful if a mine water heat pump system would be economically feasible.

One additional problem may arise if a building with a conventional oil or gas furnace is converted to a mine water heat pump system. A furnace delivers forced-air heat to a building at about 71°C. A heat pump delivers air at about 49°C, so it requires a larger flow of air for equivalent heat transfer. About twice the normal-size air ducts /or double the number/ are required to accommodate the increased flow, with a larger fan [4]. A faster fan with the original ducts would not suffice, because the efficiency of the system would be less and the noise increased. The higher air flow rates of heat pumps also require that supply and return registers and grills be adequately sized and properly located to ensure good air circulation without drafts [7]. Similarly, hot-water baseboard tubing must transmit roughly double the water flow, or have twice the surface exposure of the tube to air [4]. Thus, retrofit of buildings to accommodate a new system can be an expensive proposition. On the other hand, some systems could be switched over to a heat pump system with only minor modifications. The ideal situation is to design and install a system when a building is first being constructed.

MINING AND HYDROGEOLOGY OF THE NORTHERN ANTHRACITE BASIN, PENNSYLVANIA

Two mine water heat pump systems are currently in operation and a third is being constructed in the northern anthracite basin in northeastern Pennsylvania. The coal-bearing Pennsylvanian rocks /Llewellyn Formation/ of the northern anthracite basin are downfolded into a canoe-shaped synclinorium, trending N50°E. The structural trough is contained in two elongate valleys, the Lackawanna Valley in the northeast and the Wyoming Valley in the southwest /Figure 4/. These are divided in the middle by a structural high, the Moosic Anticline, which partially separates the underground mine complexes and groundwater flow systems of the two valleys. The Llewellyn Formation, which underlies the valleys and lower parts of the adjacent slopes, has a maximum thickness of about 670 m in the Wyoming Valley [8] and a maximum thickness of only 250 m in the Lackawanna Valley [9]. This formation contains interbedded conglomerate, sandstone, siltstone, shales, and coal. Up to 17 coal beds are present in the Lackawanna Valley [9] and at least 26 occur in the Wyoming Valley [8], ranging in thickness from a few centimeters to 8.2 m [8,9]. The dips of the Llewellyn rocks flanking the syncline are less than 10° /from horizontal/ in the northeast to 22° in the southwest [9]. The structure of the syncline, however, is not simple. The rocks within the valleys are complexly folded and faulted and contain many subparallel anticlines, synclines, and related faults, which are discontinuous and seldom over 5 km in length [10].

Overlying the Pennsylvanian bedrock in each of the valleys is a layer of Pleistocene deposits up to 92 m thick [8]. These consist mainly of kame terraces, lake sediments, and glacial outwash sand and gravels, with a thin surface veneer of till over some areas [8,9].

Coal mining was the main industry in the valleys, beginning in 1841 and reaching its peak in 1917. Since 1959, production has steadily declined and underground mining was discontinued in 1961. Although large amounts of coal remain in place, mining ceased because of the great extent of mining, interconnectiveness of the mine workings, robbing of pillars and subsequent caving, mining shallow coals underneath streams, and inaccurate records of the extent of mine workings. All of these factors resulted in a honeycomb of mines within a fractured rock matrix that was prone to flooding, breakins by surface streams, and massive infiltration rates from saturated glacial deposits. As a consequence, the cost of pumping from active mines rapidly escalated and eventually exceeded economic limits. Today, the flooded underground workings coalesce to form huge mine pools that have relatively stable elevations, but fluctuate somewhat due to seasonal variations in recharge.

In the Lackawanna Valley, most of the mine water is contained in one large underground pool /Scranton pool/ that has a high elevation in the northeast and decreases elevation toward the Moosic anticline in the southwest. Here it overflows underground into the Old Forge mine pool which discharges into the Lackawanna River at two main locations, the Old Forge borehole /a 1.07-m-diameter borehole drilled in 1962 to relieve hydrostatic pressure in the mine below/ and the Duryea outfall. The average discharge rate of these two overflows during 1967-1970 was 3030 L/s [9]. Numerous other outflows from additional mine pools upstream also contribute to the Lackawanna River for a total average mine pool outflow of 36,300 L/s in 1967-1970 [9].

In the Wyoming Valley, many mine pools exist and are hydraulically connected, to some degree, by man-made tunnels, fractured rock, faults, and buried valley material [8]. The pattern of flow between individual mine pools is extremely complex. The water generally flows from high elevations in the northeast to lower elevations in the southwest /down-valley/. Some overflow from the mines in Lackawanna Valley enters the Wyoming Valley pools, but most of the mine water is derived from surface water flowing into caved areas around the edges of the valley, seepage from tributary streams, and leakage from saturated Pleistocene deposits in upland parts of the valley.

Over much of the Wyoming Valley, the hydrostatic head in the mine pools is greater than the ground surface elevation and the Susquehanna River, which flows through the center /Figure 4/. As a result, the mine pool drains to the surface through boreholes and air shafts in lowland areas. Mine water also seeps upward through fractures and caved areas into the overlying glacial deposits. Because of high groundwater levels in parts of the valley, some drainage tunnels at river level have been driven horizontally into mines to lower mine pool elevations. The amount of water entering and moving through the underground mines in this valley has not been estimated, but must surely be a very substantial quantity.

Mine waters have caused considerable problems to the northern anthracite basin over the past 30 or more years. Water entering the underground mines caused the demise of the coal industry in the area. Now the flooded mines contribute pollution to the rivers, cause some contamination of groundwater resources in the overlying glacial deposits, and cause flooding of basements. However, within the last three years, a potential benefit of the mine water has gradually been recognized. The large amounts of water at a relatively stable temperature /13-16°C/ can be used as a source for heat pump systems.

OPERATING MINE WATER HEAT PUMP SYSTEMS

Two operating heat pump systems using mine water now exist in the Wyoming Valley, and a third is being constructed. The first system was installed at a Radio Shack at the Midway Shopping Center near Wilkes-Barre, Pennsylvania. Since November 1979, the single-story store /297 m^2 floor space/ has been heated and cooled by a heat pump [11]. A single well /20.3-cm-diameter/ is located about 61 m from the building and extends down through 41 m of Pleistocene sediments to a total depth of about 91 m. Several seams of coal were mined beneath the site, including pillar robbing. No open mine voids were encountered in the well, but the rock was extensively fractured due to subsidence [12]. The well is cased down to bedrock /41 m/ and the submersible pump is set at 29 m. Mine water is drawn up the well to the well pump, circulated through the heat pump, and returned down the same well. Some of the "used" heat pump water is recirculated back through the system, but enough water is drawn up from the mine to maintain an adequate operating temperature [12]. The mine water was tested at the time of drilling and had a pH near 7.0. No analysis of the water has been done since the operation began.

The heat pump has a mine water/refrigerant coaxial heat exchanger coil /polypropylene outer tube, cupro-nickel inner tube/ and a capillary tube expansion device for the refrigerant. The pumping rate for mine water pump is about 5.6 L/s. During the winter heating mode, the mine water enters the heat pump system at about 13.3°C and is discharged at about 8.9°C. Roughly 760,000 L of mine water per month are circulated during the winter. During the summer cooling mode, mine water enters the system at 17.8°C and is discharged with a temperature of approximately 26.7°C. Roughly 110,000 L per month are used during the summer. For the two years that the system has been operational, no problems have been experienced. Corrosion or fouling problems of the heat exchanger have not been evident.

The second operating heat pump system is in the Kingston Recreation Center, also located in Wyoming Valley near Wilkes-Barre, which opened in May 1981. The heat pump was used for cooling in the summer of 1981 and has just been switched over to heating in October. The source well for mine water was drilled about 76 m from the building, where old mine maps showed open rooms to exist in an underground mine. The depth of the mined coal was estimated to be 58 m below the land surface. Drilling proceeded to about 56 m with very little water flowing into the borehole. At 56 m, caved roof material was encountered and mine water, under great hydrostatic pressure, came rushing up the wellbore [13]. Static mine water level is about 2.1 m below the land surface and slightly above the elevation of the Susquehanna River, located about 150 m away [13]. The return well was drilled 27 m away from the production well and is 61-m deep; static water level in this well was the same. Both wells have 20.3-cm-diameter metal casings extending through glacial deposits /29 m/ and are uncased in bedrock below. A submersible pump is suspended on a PVC drop-pipe and pumping capacity is about 5.7 L/s.

One analysis of mine water from the pumping well is shown in Table 1. The mine water has relatively high concentrations of iron, sulfate, and total solutes. However, the pH is above 6.0. Because the quality of mine water was not known at the time of heat pump design, precautions were taken in the design by assuming that a poor quality, low-pH mine water would be used. The mine water does not come in direct contact with the heat pump, but rather exchanges heat with an intermediate closed loop of clean water /Figure 5/. The mine water/clean water heat exchanger is a flat plate heat exchanger; mine water flows on one side of a thin crenulated plate and clean water on the other side, all within a gasketed jacket. During the heating mode, heat is transferred from mine water to the closed loop of clean water, which in turn transmits heat to a closed loop of refrigerant in a water chiller unit /heat pump/. Heat is then transmitted to another closed loop of clean water, which is circulated through the building and passes heat on to air via water/air heat exchangers and baseboard exchangers at locations where needed. The hot water in the closed loop is also used to heat hot water during winter for domestic purposes, using a water/water heat exchanger. During the heating season, incoming mine water has a temperature of about 16.1°C and return mine water is about 11.9°C /a temperature drop of 4.2°C/.

The Kingston heat pump system was designed with ample capacity to heat the entire building during a cold winter. However, as a precautionary measure against submersible well pump or heat pump failure, an electrical resistence boiler system was installed as a backup unit. The electrical resistence heater also produces hot water for domestic purposes during summer and emergency periods.

A third mine water heat pump system in Wyoming Valley is currently being built for the Nesbitt Memorial Hospital. The hospital already has an ample heating supply, so the mine water system will be used only during the summer for cooling. Three wells have been constructed for the heat pump system. Wells 1 and 2 were drilled into about 47 m of Pleistocene valley fill deposits and both could easily produce greater than 6.3 L/s [14]. However, suspended sediment in the unscreened Well 1 caused considerable wear on the test pump, so it was decided to deepen the well down to the first flooded mine. Well 1 /20.3-cm-diameter/ hit a highly fractured rock zone at 69-m depth and stopped at 83.8 m because more than adequate water was available from the fractured zone. Presumably, the fractured rock was due to subsidence in a mine below at 114-m depth. Well 2 was designed as a return well /15.2-cm-diameter/, but during the initial pumping tests excessive sediment pumped from Well 1 coated the inside of Well 2, resulting in a decrease in permeability and excessive head buildup [14]. Well 2 was therefore deepened to the mine void, where all the water could be returned with little resistance to flow.

Well 3 is an additional supply well drilled down to the mine void /115.8-m deep/. Based on old mine maps, this area of the mine had been rock-packed /waste rock was placed in the voids for roof support/. Air circulated by the drilling rig removed some of the mine fill material, but the mine water remained muddy even after a pumping test was run. Sediment wear on the pump was extensive and the pump capacity quickly diminished. A second pumping test was run and the pump again experienced sediment wear and reduced pumping capacity. However, by the end of the second pumping test, the mine water had cleared with only a minor amount of fine coal in the water. A steel rather than bronze pump should have been used because it is more abrasion-resistent.

The wells are now completed: Well 1 and Well 3 will be the supply wells and Well 2 will be the return well. The heat pump system is not completed yet, but it is anticipated that the system will require approximately 9.5 L/s and create a 4°C rise in water temperature from the ambient 12.2°C measured in Well 1 [14]. Well 1 does not directly penetrate the mine workings, but presumably the water flows from the mine through fractured roof rock. A water analysis of Well 1 is shown in Table 1. The quality is relatively good, with a pH greater than 7.0 and sulfate, iron, and total solute concentrations much lower than measured at the Kingston Recreation Center. There should be no problem in using this water for a heat pump, assuming the water quality does not worsen when actual pumping and operating conditions begin. Water samples from the other wells in the mine void have been collected, but analyses are not yet complete.

D.O.E. RESEARCH AND DEMONSTRATION PROJECTS

The three mine water heat pump systems previously described are located in the Wyoming Valley in the Wilkes-Barre area. The U.S. Department of Energy is currently funding a research and demonstration project in the Lackawanna Valley to the northeast near Scranton, Pennsylvania. The purpose of the project is to assess the feasibility of using mine water heat pump systems in three types of buildings already in existence -- an industrial site, university buildings, and a housing project. For the university buildings and the housing project, it is planned that more than one building will be heated and cooled using a single well source. Because the three sites have buildings already in existence and using conventional heating and cooling, the uniqueness of this project is to determine if it is economically plausible to retrofit the buildings with a heat pump system. This includes finding space for the heat pump system and constructing new ductwork and piping systems in the buildings to convey air and water. The feasibility study is being conducted by A.E. Peters Associates, Scranton, Pennsylvania.

A study of available maps of the area has led to an approximation of what geologic, hydrologic, and mining conditions may exist under each of the three proposed drilling sites [15]. The University of Scranton site /Figure 6/ has three levels of subsurface mines. The ground elevation is about 236 m above mean sea level and the mine pool elevation fluctuates between 182 and 187 m, or about 51 m below the surface [15]. At this elevation, the mine pool will more than likely fill the Dunmore No. 2 mine, but will probably be absent from the Dunmore No. 1. Being near the edge of the mine pool, difficulty may arise in trying to find saturated mine voids at this site.

At the industrial site, the surface elevation is about 225 m and the mine pool elevation ranges between 182 and 187 m above mean sea level /Figure 7/. The lower two mines in the Dunmore seams are flooded and were not rock-packed in this area, so they should be capable of yielding great quantities of water. One mine level could be used for the source of water supply and the other flooded mine could be used for return water, thus hydraulically separating supply and return wells.

The third site being studied for feasibility is a housing site, consisting of closely-spaced, two-family units. One or two supply wells are anticipated to provide mine water to the houses; a heat pump would be located in each housing unit. There are nine coal seams in this area that have been mined and the lowest four are inundated by the mine pool /Figure 8/. The middle seam /Rock Vein/ is located near the surface of the mine pool and contains water only when the mine pool elevation fluctuates upward. The lower four mines should provide an excellent reserve of mine water.

The quality of mine water under the Scranton area was investigated [16], using data on the two major mine pool overflows /Duryea and Old Forge borehole/ available from the Pennsylvania Department of Environmental Resources and analyses of samples collected from a borehole and mine shaft penetrating the mine pool in the vicinity of three proposed heat pump sites /Table 1/. The mine water from the Pine Brook shaft, National borehole, and two mine pool overflows all have a lower pH than the three heat pump sites in Wyoming Valley. However, the total solutes and sulfate concentrations are less than those found in the Wyoming Valley waters. Overall, the quality of mine water in the Scranton area does not appear to jeopardize the feasibility of heat pump operation. Corrosion-resistent metal will be necessary in the heat exchangers where they come in contact with mine water.

Test holes will be drilled to determine the actual depth and conditions of the mines, mine roof rock, and mine pools under the three proposed sites near Scranton. Pumping tests will be conducted to determine potential yield, temperature, and quality of the mine pool under each site and, possibly, to identify flow directions and interconnections between different mine levels.

ECONOMICS OF MINE WATER HEAT PUMPS

Preliminary evidence indicates that the mine water heat pump systems are very economical and can save users substantial money. The small store /Radio Shack/ near Wilkes-Barre has reported savings of about $1000 /U.S./ per year with the heat pump system which equals about 66% savings over conventional fuels. Estimates for heat and hot water costs for the Kingston Recreation Center would have been $13,360 per year for oil, $16,417 per year for electrical resistence, or $7003 per year using gas; the mine water heat pump system will cost only about $5475 per year [13]. Use of the heat pump system at Kingston in summer for cooling purposes will be an additional cost savings because the heat pump is more efficient than conventional air conditioning. Design and cost estimates for the three proposed heat pump systems near Scranton are currently underway.

CONCLUSIONS

Normally, water in active mines is only considered a nuisance and sometimes a hazard. Abandoned underground mines usually fill up with groundwater and overflow into streams, sometimes causing pollution problems. However, heat pump systems could change mine water into a very beneficial and cost-saving commodity. By extracting heat from mine water during winter, buildings can be heated for much less cost. During summer, mine water can also be used for cooling purposes.

Two mine water heat pump systems are now operational and another is being constructed in the northern anthracite basin of northeastern Pennsylvania. The two operating systems are performing exceptionally well and there appears to be no problem yet with regards to the low pH of 6.0-6.7 and high iron content of 40-45 mg/L in the mine water. One system at a hospital is currently under construction and three more sites near Scranton are being evaluated for feasibility. Heat pump systems using discharges from active mines have not been attempted yet, but certainly the potential cost savings for heating and cooling buildings is great.

ACKNOWLEDGEMENTS

Information on the Radio Shack, Kingston Recreation Center, and Nesbitt Memorial Hospital heat pump systems was kindly provided by J. Yendrick, J. Peznowski, and B. Redmond, respectively. The feasibility study for three sites near Scranton is being conducted by A.E. Peters Associates and funded by the U.S. Department of Energy.

REFERENCES

1. Hughes, W.M. A technical examination of ground water geothermal heat pump components. Ground Water Heat Pump Journal, Vol. 1, No. 1, pp. 14-15 /Spring 1980/

2. Gass, T.E., and Lehr, J.H. Ground water energy and the ground water heat pump. Water Well Journal, Vol. 31, No. 4, pp. 42-47 /April 1977/

3. Anderson, D.L. Hot water in underground mining. Proceedings, International Symposium on Water in Mining and Underground Works, Granada, Spain, Asociacion Nacional de Ingenieros de Minas, Vol. 2, pp. 1111-1123 /1978/

4. Gannon, R. Ground-water heat pumps: home heating and cooling from your well. Popular Science, pp. 44-48 /Feb. 1978/

5. Nielsen, C.E., professor, Ohio State University, personal communication /1981/

6. Heiss, H.W. Research foundation utilizes ground water heat pumps. Water Well Journal, Vol. 31, No. 4, pp. 58-59 /April 1977/

7. Doty, P. Pipe and duct sizing for ground water heat pumps. Ground Water Heat Pump Journal, Vol. 1, No. 1, pp. 22-26 /Spring 1980/

8. Hollowell, J.R. Hydrology of the pleistocene sediments in the Wyoming Valley, Luzerne County, Pennsylvania. Pennsylvania Geological Survey, Fourth Series, Water Resource Report 28 /1971/

9. Hollowell, J.R., and Koester, H.E. Ground-water resources of Lackawanna County, Pennsylvania. Pennsylvania Geological Survey, Fourth Series, Water Resource Report 41 /1975/

10. Darton, N.H. Some structural features of the northern anthracite coal basin, Pennsylvania. U.S. Geological Survey Water-Supply Paper 1535-G, 18 pp. /1940/

11. Moran, E. Mine water powers heat pump. Popular Science, Vol. 218, No. 4, p. 64 /April 1981/

12. Yendrick, J., engineer, A.C.S. Industries, personal communication /1981/

13. Peznowski, J., engineer, Utility Engineers, Inc., Forty Fort, Pennsylvania, personal communication /1981/

14. Redmond, B., professor, Wilkes College, Wilkes-Barre, Pennsylvania, personal communication /1981/

15. A.E. Peters Associates, Scranton, Pennsylvania, unpublished information /April 1981/

16. A.E. Peters Associates, Scranton, Pennsylvania, unpublished information /Feb. 1981/

List of Figures

List of Tables

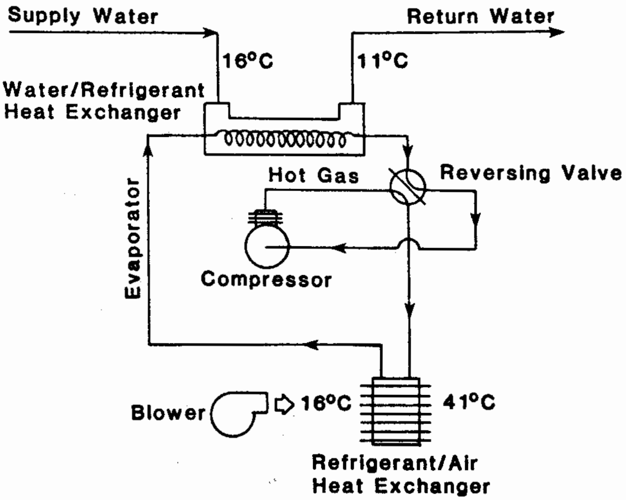

Figure 1

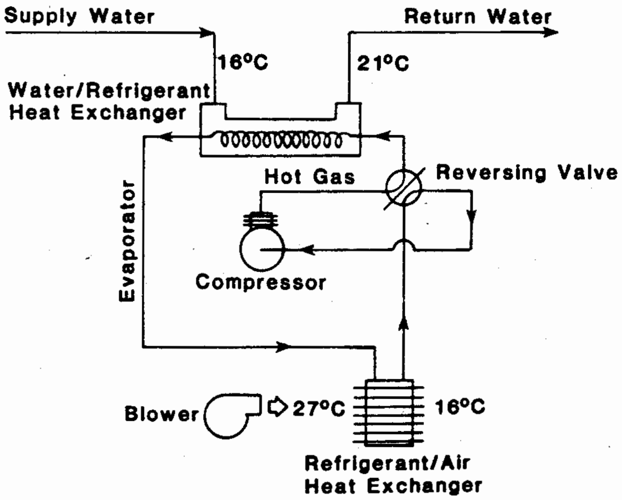

Figure 2

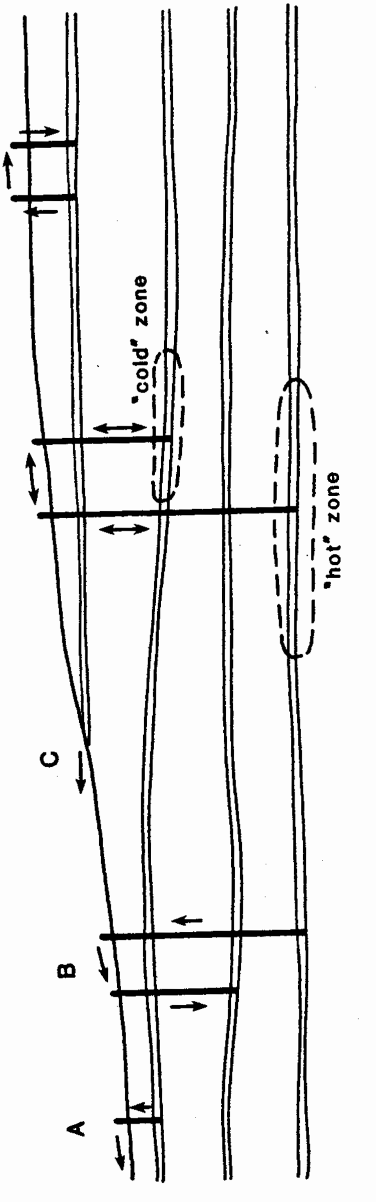

Figure 3

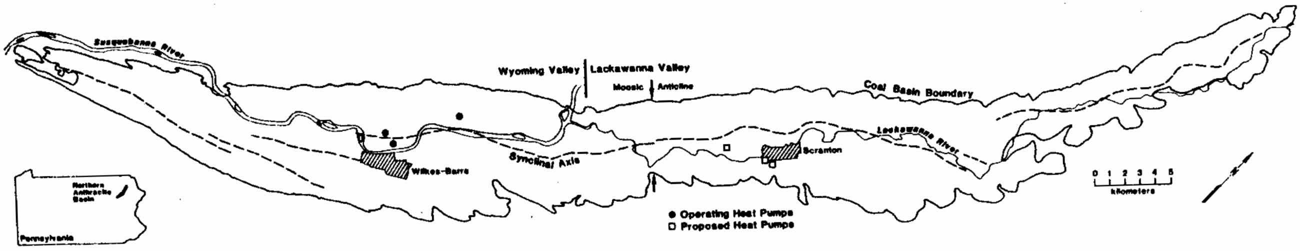
Susquehanna River
Wyoming Valley
Lackawanna Valley
Moosic
Anticline
Coal Basin Boundary
Lackawanna River
Synclinal Axis
Wilkes-Barre
Scranton
● Operating Heat Pumps
□ Proposed Heat Pumps
0 1 2 3 4 5
kilometers
N
Northern Anthracite Basin
Pennsylvania

Figure 4

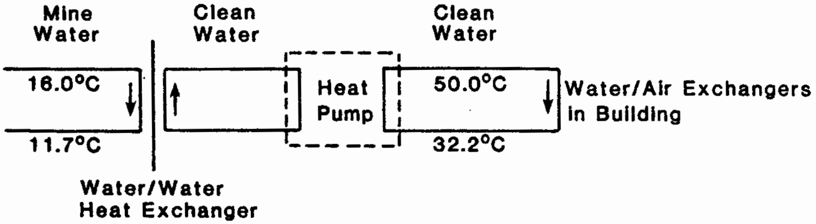

Figure 5

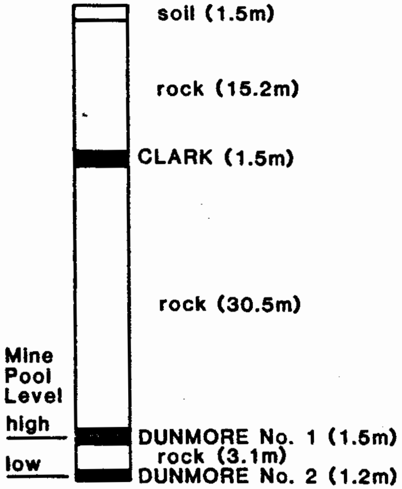

Figure 6

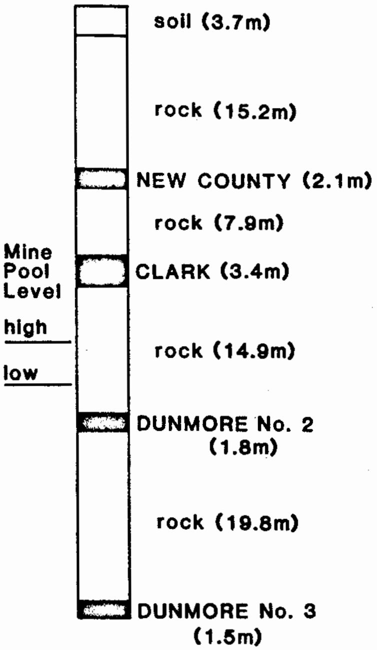

Figure 7

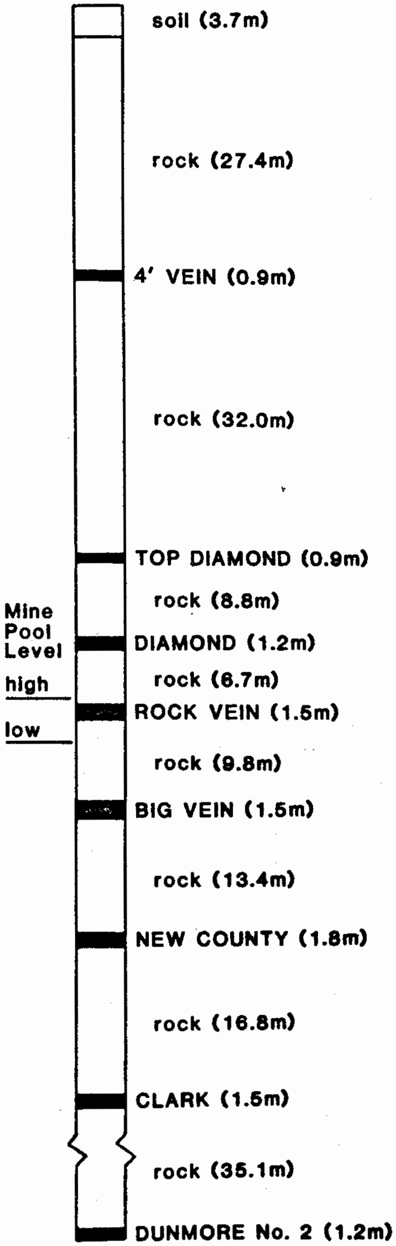

Figure 8

Table 1

	No. of Samples	Temp. (°C).	Lab. pH	Spec. Cond. (µS/cm)	Total Solutes	Acid.	Alk.	Hard-ness	Total Fe	Mn	Ca	Mg	SO_4	Cl
					(mg/L)									
Kingston Recreation Center	1	16.1	6.07	--	2115	--	190	380	42	2.53	--	--	1275	99
Nesbitt Hospital No. 1 Well	1	12.2	7.33	--	904	--	410	600	2.65	0.52	--	--	290	18
Duryea Outflow	64	--	5.54	--	--	45	38	--	47	--	--	--	597	--
Old Forge Borehole	63	--	5.72	--	--	38	43	--	41	--	--	--	611	--
Pine Brook Shaft	8	14.5	5.23	450	779	84	--	740	40	4.25	150	105	483	106
National Borehole	6	15.0	5.62	138	562	50	--	500	173	6.0	92	77	406	52