OPEN LOOP GEOTHERMAL WELL SYSTEMS ON LONG ISLAND

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Introduction

The use of groundwater for cooling and heating purposes on Long Island dates back as early as the 1930's. Long Island's abundance of readily available groundwater supplies with constant water temperatures allows for technologies relying on groundwater acting as a heat pump to be employed cost effectively and efficiently.

Numerous methodologies exist to use this abundant natural resource as a renewable energy source in an efficient and environmentally friendly manner for heating and air conditioning industrial, commercial, institutional and residential structures.

The more common systems utilized on Long Island are ground source heat pumps or geothermal systems involving open or closed loops. Another type of system also found on Long Island, though not quite as numerous as the others, is a standing water column system. This system is a hybrid of open and closed loop systems, though more closely resembling closed loop systems.

A brief overview of open loop ground source heat pump or geothermal systems is presented in this paper. The operating principles, important design criteria, hydrogeology and operation and maintenance procedures are introduced. Some field experiences and lessons learned are also discussed.

Different Types of Systems Typically Found on Long Island - Overview

Open loop geothermal systems typically include one or more supply wells and one or more diffusion, recharge, return or injection wells. In an open loop geothermal well system, groundwater is withdrawn from an aquifer through the supply well and pumped to a heat exchange device where it acts as a heat source or sink in the heating or cooling process. A typical heat exchange device is a plate heat exchanger, in which a non-contact, non-consumptive process takes place between the groundwater and the building's internal circulation water. Heat is transferred between the two waters without ever physically coming into contact or mixing with one another. Once the groundwater passes through the heat exchange device it is returned to the aquifer through a diffusion well(s). The only difference between the supply and return water is the temperature. The open loop system is one of the more common systems found on Long Island and is utilized in both large and small scale applications.

Closed loop ground source heat pump systems do not involve wells but rather a series of deep boreholes (usually 300'+) fitted with long narrow u-tube configurations of piping. The boreholes are drilled deep below the water table and rely on the soil mass and groundwater to act as the heat source or sink for the water being pumped through the tubes within the boreholes. The water within the tubes never physically contacts the groundwater and groundwater is not withdrawn from or recharged to the aquifer. The water within the tubes is simply circulated between the boreholes and the building's heat exchange device. Again, the only exchange between the water within the borehole tubes and the groundwater and soil mass is a thermal one. The closed loop type of geothermal system involving boreholes is gaining popularity on Long Island due to its ease of maintenance and can be utilized in both large and small scale applications. The major draw back to this type of system is that a large number of boreholes are usually required and spacings between boreholes can vary between 10 to15 feet, thus a large area of land is often required.

A standing water column system is generally a single deep well drilled into bedrock. A casing is set from grade down to bedrock and from there the well is essentially an open rock well. The geothermal water in this case is circulated within the same well. Here, if the water is withdrawn from the bottom of the well the water will be returned at the top and allowed to heat or cool as it traverses down the well to where it is being withdrawn from. In most instances the bedrock is fairly impermeable and less than 10% of the water being pumped from the well is "new" or "fresh" groundwater. Hence, this type of system behaves primarily as a closed loop ground source heat pump. Due to the large depth of bedrock on Long Island these systems are not very common, are generally limited to the north shore of the island, and typically used in small scale applications such as residential projects.

Open Loop Geothermal Well Systems - Operating Principles

The groundwater side of an open loop geothermal well system operates in a fairly simple and straight forward manner. Groundwater is pumped from a supply well and recharged through diffusion wells. Pumping ranges for these types of systems on Long Island vary from tens of gpm up to hundreds of gpm and in some large systems, over 1,000 gpm.

What happens to the groundwater between the supply and diffusion wells can vary based on the complexity and importance of the system. Larger systems are generally found in hospitals, schools, industrial and commercial buildings and apartment complexes. In these instances the system is relied on heavily for providing air conditioning and heating and will require a more serious control and monitoring methodology. With the larger systems, after the groundwater is withdrawn from a supply well it will be pumped through a piping system where it will pass through various control devices, monitoring equipment, instrumentation and a heat exchanger before being returned. Figure 1 depicts a schematic of a typical large system with the different types of controls often necessary for an open loop geothermal system to operate optimally.

Groundwater is withdrawn through the supply well using a pumping unit, usually a submersible pump. An in line check valve either integral to the submersible pump or installed in the discharge column is often specified to prevent the system from partially draining on shut down. This helps minimize air from entering the system. Gate valves are part of the piping system that can be used to isolate certain aspects of the system depending on the circumstances. For instance, if multiple supply or diffusion wells are part of the system a gate valve may be closed to isolate one of the wells while maintenance procedures are being performed on it. Thus allowing the rest of the system to continue to operate. Air relief and vacuum breaker valves are generally installed in critical locations in the system such as at high and low points and at well heads. These types of valves help reduce the amount of air in the system and alleviate many of the problems air can cause, such as poor heat exchange and entrained air in the return water.

Other important control devices include strainers and throttling valves. Strainers can be of particular importance if a supply has a tendency to pump

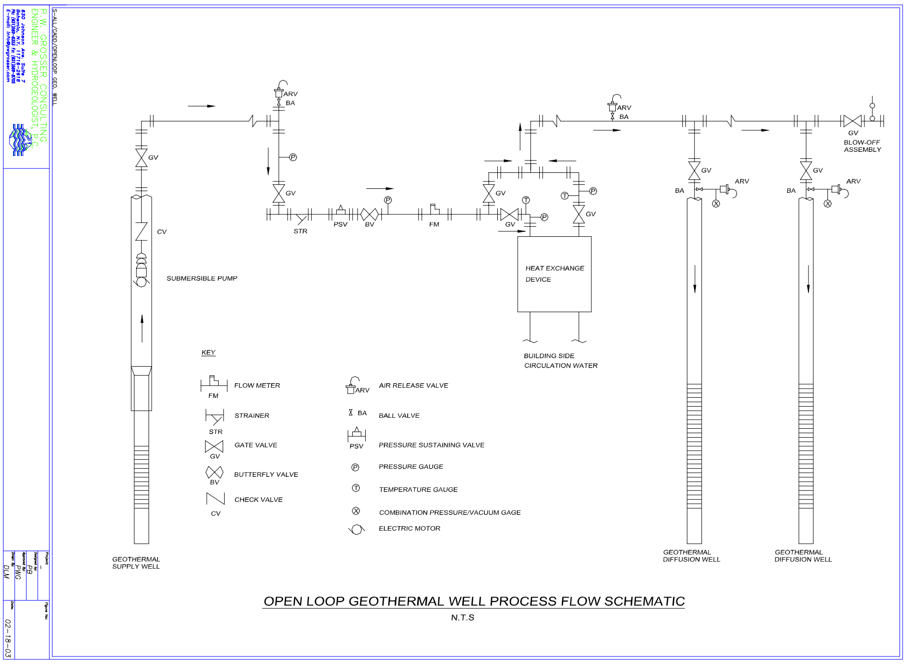


Figure 1 - Open Loop Geothermal Well System Schematic

sand. The sand will ultimately end up in the diffusion well and likely start to plug the screen zone and reduce the overall capacity and efficiency of the diffusion well. An in line strainer will remove large particulate matter and prevent it from ending up in the diffusion wells. A throttling valve, such as a butterfly valve, can be used to control the flow from the supply well by increasing or decreasing the amount of back pressure the pumping unit is working against. This is particularly convenient for conducting pump tests to gage the overall efficiency of the pumping unit and if a variable flow is desired during system operation. Another way to vary the flow of the geothermal system is to use a variable frequency drive (VFD) on the pumping unit motor. Here the motor rpms are varied by changing the frequency of the electricity being used by the motor. As the rpms the motor and subsequently the pump impellers spin at varies, so does the flow rate through the system.

Monitoring how well the system is operating can be accomplished using different instrumentation apparatuses. These may include: flow meters, pressure/vacuum gauges, thermometers and water level sensors.

Design Criteria for Open Loop Geothermal Well Systems

Design of open loop geothermal well systems requires detailed knowledge of the local hydrogeology and an understanding of the hydraulics involved with the piping and heat exchange portion of the system. The most critical aspect of the design involves the aquifer system from which groundwater is being withdrawn from and recharged to. Since the wells are the key to tapping and utilizing the groundwater, they need to be carefully sized and located. When designing these types of wells the usual aquifer parameters such as porosity, hydraulic conductivity, transmissivity, storativity and aquifer thickness, are sought out through research of published works about the local area, obtaining data from nearby existing wells or through conducting actual field tests. Obviously, conducting actual field tests is the most preferred and accurate method to obtain data specific to the project, but is often economically infeasible especially for smaller projects such as residential applications. Depth to water and groundwater flow direction are also important pieces of aquifer information to obtain.

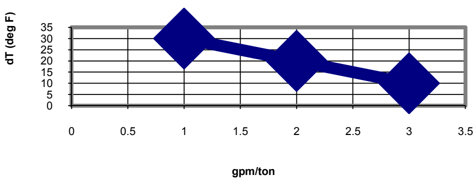
If field tests are to be conducted, test wells are installed, split spoon samples collected, water quality samples analyzed and the boreholes logged both visually and geophysically. Pumping tests are conducted and the results are analyzed to estimate the key aquifer parameters. Borehole logging helps establish the lithology, stratigraphy and depth to water.

Once the appropriate information is collected well design begins. The flow rate of geothermal water is generally dictated by the acceptable temperature differential between the supply and return waters and the cooling/heating loading of the building. Lower flow rates will mean a higher temperature differential. Higher temperature differentials will require larger separation distances between the supply and diffusion wells to avoid or reduce the effects of thermal breakthrough. This phenomena occurs when the supply water temperature begins to change from ambient groundwater temperatures (commonly 50EF to 55EF for Long Island) because the recharge water that is returned to the aquifer is now influencing the supply well. Geothermal water requirements, based on the cooling or heating demand of a facility, are typically expressed as gallons per minute per ton of cooling or heating load (a ton being equal to 12,000 Btu/hr). Temperature differentials can be approximated based on the following simple linear relationship:

1 gpm/ton, ♠T = 30EF

2 gpm/ton, ♠T = 20EF

3 gpm/ton, ♠T = 10EF



The faster water moves through the system the lower the temperature differential between supply and return waters. Thus if a site is limited in areal extent, the designer may need to consider going to a higher flow rate system.

After the system flow rate is established, well location is addressed. Supply wells are recommended to be sited upgradient and as far away as possible from diffusion wells, again to reduce the potential effects of thermal breakthrough. If multiple supply and diffusion wells are to be implemented the wells should be spaced as far apart as is economically feasible to limit the effects of drawdown and mounding. Diffusion wells spaced too closely together can have negative effects on one another. They can create excessively high mounds in unconfined aquifers or increase the potentiometric surface so much in confined aquifers that they no longer behave as gravity diffusion wells but become forced injection wells. This effect will create higher backpressures on the system pumping units and ultimately cause lower flow rates, higher temperature differentials and disrupt the system's overall efficiency and performance (i.e., no longer meeting the building's cooling and heating needs). Therefore extreme care must be taken in properly locating and spacing wells. A good understanding of the local hydrogeology and well hydraulics is necessary to properly locate open loop geothermal system wells. In many cases numerical groundwater modeling is conducted during the design phase to estimate to what degree impacts can be expected based on different well location and pumping/recharging scenarios.

With the flow rate and general well locations determined the wells are then designed as typical water supply wells. The well screen diameter, length and slot size are based on the required flow rate, desired screen entrance velocity and the grain size distribution of the aquifer it is to be situated in. The overall depth of the well and the screened interval are computed based on aspects such as static depth to water, drawdown, required pumping unit submergence and the location of high conductivity water bearing strata in the aquifer.

A difference between supply and diffusion well screen design is that typically it is much more difficult to return water to an aquifer than it is to remove it. Many theories have been posed as to why this is the case, but none that the authors are aware of have been proven to be the universal case. To compensate for this effect it is generally recommended that two to three times the amount of screen be provided on the diffusion end of the system as opposed to the supply side. Experience has shown that substantially more than this may be necessary in some instances. Additionally, diffusion wells have a greater tendency to become fouled and require maintenance more frequently than supply wells. Often more diffusion wells, than are theoretically necessary, are installed for redundancy and to keep the system operational while maintenance procedures are conducted.

Long Island geothermal wells are required by the NYSDEC to be screened within 50 feet vertically of one another and be situated within the same aquifer unit. In other words, the water removed from an aquifer must be returned to that same aquifer and not by more than a 50 feet vertically in either direction (i.e., above or below). Therefore, the bottom of a supply well can not be more than 50 feet above the tops of the diffusion wells it is discharging to and vice versa. Also no confining units may exist between the screen zones of the wells. Taking these criteria into consideration can further complicate system well design.

Water quality is a design variable that is often overlooked. Groundwater with high quantities of dissolved inorganics such as iron, calcium and manganese can cause serious diffusion well problems. As the groundwater is returned to the diffusion well it cascades down the well casing before reaching the water surface. The water goes through an aeration process where many of the dissolved inorganic constituents can precipitate out of solution and begin to accumulate in the screen zone and reduce the well's overall diffusion capabilities. Also using the water as a heat sink can cause scale deposits to form as a result of the presence of excessive amounts of calcium and manganese. The local water quality needs to be carefully evaluated during the design process to ensure that the system will not be adversely effected be these parameters. As the process is a non-contact, non-consumptive one, treatment of the water is prohibited. Therefore, if unacceptable water quality exists an open loop geothermal well system may not be appropriate.

Hydrogeology and Open Loop Geothermal Well Systems

Hydrogeology plays important part in the design of an open loop geothermal well system. Fortunately much is known about Long Island's hydrogeology across most of the island. A significant amount of published material exists and can be used as a preliminary screening tool in determining the applicability of using an open loop type system. The significant parameters that need to be evaluated when considering an open loop geothermal well system include: depth to water, porosity, specific yield, hydraulic conductivity, specific capacity, and what type of aquifer conditions are present (i.e., confined, unconfined, etc.).

Depth to water is important because generally the greater this distance the better off the diffusion side of the system will perform. A large depth to water unfortunately increases the horsepower size of the pumping unit motor, but allows for a large recharge head to be developed in the casings of the diffusion wells. Also, if mounding is a concern in the diffusion well area, larger mounds can be accommodated. Generally, as the depth to water becomes more shallow, especially in unconfined aquifers, open loop geothermal systems become less and less desirable. For most Long Island systems, a depth to water of 35 to 40 feet is usually adequate. Successful systems have been installed with shallower depths to water, but, if the formation begins to plug or the water table rises, localized problems such as aquifer saturation and flooding have been known to occur. Larger or higher flow rate systems will require larger depths to water to ensure operation as a gravity type diffusion system.

The porosity of the formation from which water is being supplied and returned needs to be investigated. The more coarse or the more porous the material in which an open loop geothermal well system is to be installed the better. Coarser formations can provide and accept water more readily than tighter, finer ones. As mentioned, it is generally more difficult to recharge the groundwater than it is to remove it, therefore a coarse medium with a high percentage of void spaces will lend itself more readily to the diffusion process. Most Long Island open loop geothermal well systems are installed in the Upper Glacial and Magothy aquifers. The Upper Glacial aquifer is generally described as a sand and gravel aquifer with varying porosity. Porosities below 0.15 can make using open loop geothermal well systems difficult.

Porosity however should not be the only criteria considered when evaluating an open loop geothermal system. Clays can have high porosities but extremely low hydraulic conductivities. Hydraulic conductivity is an indicator of the aquifer's ability to transmit water. Low hydraulic conductivity formations are obviously unsuitable for open loop geothermal well systems. Long Island open loop geothermal systems have been installed in various hydrogeological settings with hydraulic conductivities that range from on the order of hundreds of gpd/ft^2 to over 2,000 gpd/ft^2. The better performing or more efficient systems have higher hydraulic conductivities associated with them (i.e., fewer diffusion wells, less diffusion well screen). The higher hydraulic conductivities associated with the Upper Glacial aquifer, as opposed to the Magothy or Lloyd aquifers, make it the most desirable aquifer for an open loop type of system.

Specific capacity is a basic measurement of a well's efficiency. Specific capacity is dependent on several variables that include: well screen length, diameter and slot size, gravel pack size and the type of material that the well is situated in (i.e., gravel, sand, silt, etc.). This parameter gives good insight into how well an aquifer, and the wells installed in it, are interacting to produce and accept water. The higher the value of this parameter the better. Assuming most wells are properly and similarly designed and constructed on Long Island (i.e., using the same methodologies, procedures and materials), this value can be assumed during the design phase to be typical for the area where the system is to be installed. Values for the Upper Glacial aquifer are reported to range between 10 to 200 gpm/ft. Open loop systems may become difficult to implement in areas where the specific capacity is less than 10 gpm/ft, especially larger systems.

What type of aquifer the system is being installed in also plays an important part in how the system is designed and how well it will perform once constructed. Confined, unconfined and semi-confined aquifers or portions of aquifers can be found on Long Island. Depending on the type of aquifer, different properties will be associated with it and need to be taken into consideration when designing and constructing open loop geothermal wells.

Geothermal Well Rehabilitation

An effective maintenance program is essential in order to keep a well at its maximum efficiency. As a well ages, its ability to produce or diffuse water decreases as the screen slots slowly become plugged. Well rehabilitation, which is the restoration of a well to its most efficient condition, to any well is eventually inevitable. The necessity of rehabilitation will depend on how often and effectively the wells are maintained. In some cases, damage to a well may be so severe that screen replacement or lining may be necessary. More often the well can be chemically treated in the hopes to disrupt, dissolve, or remove deposits in the well or the surrounding aquifer.

Declining well capacity may be the result of a number of different problems. Well yield may be reduced by chemical or biological encrustation, silt or clay intrusion, and mineral deposits. The type of problem is often related to the type of aquifer the screen is placed in or the quality of the groundwater. For example, on Long Island iron in the groundwater is very common and this can accelerate deterioration of the well screen zone. Mineral deposits in the screen zone will effect the well's diffusion capabilities as well as its ability to produce water.

Before a treatment process can be determined the problem must first be identified. In most cases a problem is indicated as a result of a well's declining well capacity. Specific capacity is defined as the flow rate divided by the draw down of the water column. Observing a decreasing specific capacity will often provide the initial insight to potential well problems that will likely require rehabilitation efforts to correct. Increased power usage, i.e., amperage draw or voltage drop may also indicate a well related problem.

The first step to identifying the type of problem is performing a televised well inspection. In this process, a submersible camera is lowered into the well and the interior condition is video logged. Encrustations and slimes in the well or screen can usually be identified on the monitor and the color can most times identify the type of problem. Samples of the formation immediately surrounding the well may also be collected and analyzed to determine the type of buildup.

Once the type of problem is identified, the second step is deciding a treatment process, which is mostly dependent upon whether the problem is geochemical or biological. Types of rehabilitation or cleaning agents include: wetting agents and surfactants which form chemical "bridges" between solids and water helping it to suspend the solids; dispersants which penetrate and interfere with the chemical attraction of deposits; chelaters which combine with metal ions to keep them in suspension; and disinfectants which kill microorganisms. In a case where there is an inorganic buildup in the screen zone, hydrochloric acid (HCl) may be used.

Before a well is treated the contractor will first want to brush the well with a wire brush to remove and loosen debris. Following this procedure the sump of the well should be bailed, removing as much accumulated debris and sediment as possible. Chemical treatment will then be introduced into the well. Each treatment should consist of approximately three well volumes to allow for the solution to disperse into the formation. A tube called a tremie pipe should be used to deposit solution directly into the screen zone, in turn reducing the dilution effect and also preventing the solution from reacting with the casing above the water table. The solution should then be allowed to stand at least overnight.

There are a number of other techniques that may be used in conjunction with chemical treatment. Some examples include: surge blocks, jetting, air bursting or blasting, high-pressure air lifting, and sonar jetting. These are all variations of physical methods meant to agitate the formation and break up materials with the use of force.

Upon completion of treatment, the waste must then be pumped off and properly disposed of. In general it is necessary to pump off approximately ten times the volume of the chemical solution that was put into the well in order to clear it out. Some chemicals can become a bacterial substrate after dilution so clearing out as much as possible is essential. Prior to disposal it is important that the waste is neutralized before being released into the environment. Once treatment and disposal is completed, a second televised inspection will usually be performed in order to ensure that most of the buildup has been removed.

Once well rehabilitation procedures are completed a performance test should be conducted in order to confirm that the treatment was effective. The performance test should be carried out between four to 12 hours and involves pumping the groundwater from the supply well(s) into the diffusion well(s). The water can be either pumped directly into the diffusion well(s), or may be run through the heating/cooling system prior to recharging through the diffusion wells. Preference is for conducting the test utilizing the entire system to observe system operating temperatures and pressures. During testing, water levels in each well should be recorded periodically throughout the test. In addition, the pumping rate and well head pressures/vacuums should also be recorded. Observation of these criteria will allow the performance of the rehabilitated system to be observed and compared to specified operating values.

Wells are often allowed to deteriorate for such a long time that their specific capacity may be impossible to restore completely. Rehabilitation procedures should be initiated before the specific capacity has declined 25 percent. For this reason, it is essential that the well owner keep good well records so that and decline in performance will not go undetected.

Conclusion

Open loop geothermal well systems are a proven, efficient, and reliable alternative cooling and heating method that can be used in a wide array of different applications. Long Island's vast natural resource, groundwater, is an excellent heat source/sink that can be easily tapped and used in such systems. Geothermal systems are often encouraged by local utility companies because of their efficiency and ability to help reduce energy consumption. Rebates of up to $350/ton with a maximum of $100,000 per project have previously been offered by LIPA to help encourage the use of these types of systems on Long Island. The rebates are offered to help off set the often larger capital cost associated with geothermal systems as opposed to the more conventional systems (i.e., cooling towers, dry coolers, etc.). The increased efficiency of geothermal systems over conventional systems helps quickly pay for them and savings are often seen within a few short years after installation.

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