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Bioresource Engineering Design 1

September 19, 2008

Geothermal Energy and Sustainable Design

The desire for fossil fuel alternatives and environmentally friendly energy has grown dramatically in recent years. As fossil fuel costs have sky rocketed, environmentally friendly energy sources such as wind, solar, and geothermal have become more economically viable and have received increased attention. According to the US department of energy, geothermal energy holds the greatest energy potential out of all our current energy sources (6). In order to asses the feasibility of the application of geothermal energy in a sustainable design development, we will look at what is meant by geothermal energy, the variety of energy capture mechanisms that are currently available, the environmental impacts associated with geothermal energy capture, costs, and practical applications.

Geothermal Energy

Geothermal energy is defined as energy derived from the natural heat of the Earth contained in hot rocks, hot water, hot brines or steam. Many different technologies have been developed to utilize geothermal energy. The heat can be extracted through a variety of sources. Heat from hot water or steam basins located deep within the earth surface can be retrieved by drilling. Geothermal reservoirs that appear near the earths surface can be accessed directly, and areas of shallow ground that sustains a steady temperature, generally between 10 to15 degrees Celsius, can be used by geothermal heat pumps.

Hydrothermal

One of the major means of geothermal energy capture is through a hydrothermal system. A hydrothermal system utilizes a geothermal reservoir that transmits heat energy upward by vertical circulation of fluids driven by a variation in fluid density that correspond to differences in temperature. Hydrothermal systems are generally classified as being vapor-dominated or hot water-dominated depending on whether the fluid extracted is in a liquid or gaseous state (7). High temperature geothermal resources exist where magma infiltrates the upper crust of the earth. This molten rock heats the surrounding rock, and in areas where this heated rock is porous enough to permit circulation of water, the subsequent hot water or steam is the hydrothermal resource. These resources are currently being used for the production of geothermal power, and are applicable in the field of sustainable design due to the continuous recharge from groundwater infiltration and subterranean heat flows. Although hydrothermal systems show great sustainability and energy efficiency in large scale applications, they show limited practicality in providing energy for a small scale sustainable development.

Deep Geothermal Systems

Deep geothermal systems, also referred to as enhances geothermal systems, are engineered basins that have been fashioned to extract heat from economically unproductive geothermal sources. Deep geothermal systems are put to use in hot dry rock areas. The deep geothermal system extracts heat by creating an artificial fracture in the rock to which water can be supplied through injection wells. As the water is exposed to the rock it is heated and flows upward to the power plant through production wells, mimicking natural hydrothermal systems. Deep geothermal systems can be employed virtually everywhere provided you can drill to sufficient depths, but capital costs can be particularly high. In most scenarios, the capital costs are considered feasible, so long as the power plant is sufficiently large. Deep geothermal systems have great potential in solving broad energy demands, but show little promise for application on a small scale sustainable development.

Geopressure Energy

Geopressure-geothermal brines are super heated waters that exist between 12,000 and 20,000 feet below the surface of the earth. Methane also exists in a dissolved state within these super heated brine mixtures. Several geopressure resources are scattered across North America. They possess a distinct advantage over other means of geothermal energy capture in that geopressure systems can be exploited for its thermal properties, chemical attributes (dissolved methane), as well as mechanical properties through the use of hydraulic pumps. In order to obtain a better understanding the potential energy available in geopressure aquifers along the Gulf Coast, the federal government launched a geological survey to estimate the available energy in that area.

The United States Geological Survey concluded that the basin in the northern Gulf contained approx. 170,000 quads of energy (6). To put this figure in perspective, the average rate of energy consumption in the US is about 85 quads per year. From a sustainability perspective, the thermal capacity of this geopressure basin is self sustaining, and the methane deposits exist in a quantity large enough the power the US for 750 years. This resource, along with many other geopressure resources can be considered inexhaustible for all foreseeable practical applications, however, high capital and operating costs limit these resources to large scale applications.

Magma Energy

Although still in theoretical stages of development, magma energy is noteworthy due to its energy abundance and unique applications. Some propose that magma could be used to induce high temperature chemical reactions to make fuels such as methane and hydrogen (4). Theoretical energy costs as low as $0.056 per kWh through use of magma energy will no doubt encourage further pursuit of this resource, but as with hydrothermal, deep geothermal, and geopressure systems, magma energy shows no practical application on the small scale.

Environmental Impacts

The environmental sustainability of geothermal energy is one positive environmental attribute, however, that is not the only parameter by which its environmental impact should be evaluated. Other aspects of geothermal energy use that must be considered include land and water use, noise, gaseous emissions, possible liquid effluents, solid waste byproducts of development, and seismic and subsidence risks. As far as reduction in point source pollution is concerned, many geothermal systems border on emission and waste free operations. We can help control water consumption by using total reinsertion and non-evaporative cooling. Noise levels of operation in a geothermal energy plant are generally controlled by silencers, but are still audible and can be considered a form of noise pollution. In specific geothermal systems in which flashed steam cycles do not use total reinsertions of fluids, dissolved carbon dioxide can be released into the atmosphere. These CO2 effluents range from .01 to .05 million metric tones of carbon per quad of energy. These effluents are, however, minimal in comparison to the CO2 effluents of coal burning power plants (29 million metric tones carbon per quad of energy) and oil (21 million metric tones carbon per quad of energy). Hydrothermal reservoirs also produce very low SOX and particulate emissions. Closed loop hot dry rock systems have projected emission levels of 0 ppm CO2, NOX, SOX, and particulates.

Geothermal energy has obvious potential for reduction of greenhouse gas emissions by replacing fossil fueled electric plants with geothermal electric plants and replacing fossil fuel boilers with direct heating applications. Replacement of stationary energy systems (80 percent of our energy usage) with geothermal energy systems could greatly reduce carbon emissions, but geothermal energy also has application in mobil energy systems. Geothermal production of hydrogen for automobile hydrogen fuel cells could provide a zero carbon-emitting vehicle.

Geothermal Heat Pumps

Geothermal Heat pumps appear to be the only geothermal energy used today that shows promise in application on the small scale. A “geothermal heat pump” is the general term for any heat pump that uses the earth’s thermal capacity as an energy source to add heat to a system or as an energy sink to cool a system (2). At shallow depths, between 3-6 feet, the earth maintains a relatively invariable temperature that is generally warmer than the ambient air temperature in the winter and cooler than the ambient air temperature in the summer. Typical levels of performance of geothermal heat pumps are very high. According to a study conducted by the EPA (1) geothermal heat pumps can reduce energy consumption by 23-44% when compared to air source heating and 63-72% when compared to electric heating and cooling.

Geothermal heat pumps are classified into three categories: ground-coupled, ground water, and hybrid (2). In a ground coupled heat pump, a closed loop of piping is buried (either horizontally below the frost zone, or vertically from 30 to 120 meters deep) and connected to a second loop inside a building. In the winter, the loop is filled with a type of antifreeze that absorbs heat from the closed loop in the ground and carries it to the building. In the summer, the process is reversed, and heat is absorbed from the inside of the building and deposited into the ground. In addition, some of the surplus heat extracted by the geothermal heat pump can provide household hot water at a low cost. (3)

Groundwater heat pumps are the oldest method of geothermal heat capture in the united states and have been used since 1930 (1). In the system, the ground water from an underground aquifer is carried to a heat exchanger that is installed in the heat pump system. As the water passes through the heat exchanger, is absorbs heat from, or delivers heat to the loop as desired. The ground water that has been pumped to the surface can then be delivered back to the aquifer through an injection well, or in some instances it is released on the surface. The preferred method of ground water disposal in a sustainable design development is the use of an injection well to help preserve our groundwater by returning used water to the underground aquifers.

The third type of geothermal heat pump is a hybrid system. The hybrid system uses a ground-coupled system in conjunction with a cooling tower. With a hybrid system, the design only needs to meet maximum heating requirements, and the cooling tower can be employed to make up for additional energy needed during peak cooling loads. The cooling tower serves the dual purpose of preserving energy in the system and reducing capital costs attributed to installation of ground loops. In hybrid geothermal heat pumps, cooling tower maintenance must be considered (4). Cooling towers used as auxiliary heat rejecters require additional maintenance.

The primary objectives of the utilization of geothermal heat pumps are to reduce heating and cooling costs. Geothermal heat pumps conserve energy and save money because the equipment functions with greater efficiency than traditional systems. Compressors in the individual heat pumps of a geothermal heat pump can operate at a higher efficiency than air source units because geothermal temperatures are much more stable than ambient air and do not produce temperature extremes. Also, geothermal heat pump systems do not require a defrost cycle or electrical resistance heat for low ambient air temperatures (2).

Given that the geothermal heat pumps are the only type of geothermal energy that could be applied to a small scale sustainable development; a designer must decide which of the three systems would best meet the desired design parameters and objectives. Although geothermal heat pumps are limited to applications in heating and cooling, the energy information administration estimates that space heating and air conditioning account for 53 percent of domestic energy usage (5), so there is still potential for dramatic energy cost reduction. In terms of sustainability, all three systems are virtually inexhaustible when designed properly; however, a load imbalance can lead to an elevation of ground temperature and decreased system performance. This is not a problem for systems that are designed sufficiently large for their energy load bearing purposes, but increased size of ground heat exchangers or distance between heat exchangers can lead to a higher capital cost. When properly designed, all systems can also be considered environmentally friendly. They do not directly contribute to any greenhouse gas formation or the introduction of byproducts of any kind to the environment (once again, assuming proper design and no leeching from closed loop systems). Based upon the assumption that all three systems are both sustainable and environmentally friendly, cost will be a major deciding factor for which method will be utilized.

Costs

When deciding what type of geothermal heat pump would be most effective for use in a given system, a variety of environmental factors must be considered. No one method is optimal for all geological locations, but the cost benefits of each system have generally been determined. According to a cost comparison conducted in the Geo-Heat Center at the Oregon Institute of Technology, hybrid systems are favored in scenarios where ground loop costs are high (i.e. rocky surface/hard to dig), groundwater systems incur a substantially lower capital costs over hybrid and ground coupled systems and ground-coupled systems can be installed easily in areas with favorable soil conditions and limited ground water resources (8). Costs vary greatly on a case by case basis, and the ultimate decision must be made only after gaining an extensive understanding of the geological properties of the area being developed (2).

Some additional considerations for geothermal heat source and sink can arise depending upon availability. If groundwater is already being pumped, treated, and re-injected as part of a ground water remediation project, utilization of that existing source could be economical. If large volumes of stationary water are available on site heat exchangers can be put in contact with reservoirs, reflecting pools, ponds, lakes, and run off retention basins. In this case, sensitivity of local fish to water temperature flux must be considered, but the reduced energy costs can be substantial (3). Large rivers with minimal variation in the quantity of water flow can be utilized as a heat sink through use of a submerged pipe loop. If sufficient ground water is available a plate and frame heat exchanger can be used. Re-injection costs must be considered in this case but are generally minimal.

Case Study (Fort Polk)

In an independent case study conducted by Lockheed Martin's Oak Ridge National Laboratory, the effectiveness of a 4003 home geothermal heat pump retrofit at Fort Polk, Louisiana was evaluated. The report concluded that through the replacement of heating, cooling, and water heating systems in the houses with geothermal heat pumps the installation as a whole will save 25.8 million kilowatts per hour. This translates to a savings of 32.5 percent of the community electrical consumption prior to the renovation and 100 percent savings in use of natural gas which has previously been used for space conditioning and water heating (8).

These savings led to an estimated CO2 emission reduction of 22,400 tons per year. In addition, the peak electrical demand was brought down by 7.55 megawatts, or 43.5 percent of the demand prior to the retrofit. The reduction in energy demand corresponds to an improvement in the community yearly electrical load factor, which increase from .52 to .62.

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