ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY GENERATION AND UTILIZATION

Luis D. Berrizbeitia
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Hamburger, Rupp and Taranovic
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Abstract

Geothermal energy has been used for centuries throughout the world. Recently, because of a push to diversify forms of energy away from fossil fuels, geothermal energy has been researched and utilized to great effect. Geothermal energy is prevalent mainly on the west coast of the US and other countries lying on the 'ring of fire'. Geothermal energy is considered a renewable resource and the emissions from plants are slim to none when compared with other fossil fuel powered plants. Although geothermal energy is much more environmentally friendly than other types of energy production, there are still aspects of geothermal energy plants that can be harmful towards the environment. This paper aims to give an overview of geothermal energy globally, and within the United States; its victories, shortcomings, and current status.

Introduction

Geothermal energy is power derived from the earth's own internal heat. This heat, or thermal energy, is contained within the earth's rocks and in the fluids and water that are under the crust of the earth. Geothermal energy can be found at varying depths from the surface, from fairly shallow reservoirs to very deep ones. The hottest depository of heat is the molten rock or magma. Because it is clean and renewable, geothermal energy is being promoted as one of the best alternatives to fossil fuels.

About 20% of the geothermal energy originates from the energy remaining from the original formation of the planet and the rest from radioactive decay of minerals. Thermal energy is a term used to describe the total energy of a piece or sample of matter that exists as a consequence of absorption or generation of heat. Thermal energy does not include other sources of energy in matter such as the energy stored in the chemical bonds within and between atoms or the energy stored with the atomic nucleus itself. Heat absorption generates random motions of the systems system's constituent particles which include atoms, molecules, electrons, and sub-particles. These motions produce both potential and kinetic energy that can be transferred across a temperature gradient to other pieces of matter. Geothermal energy is the result of thermal energy transfer from core to the crust of the earth.

The difference in temperature between the core and the surface of the earth is known as the geothermal gradient which drives a continuous conduction of thermal energy as heat to the surface of the earth Thermal energy generated from radioactive decay depends on the presence of radioactive isotopes present since the formation of the earth with the major heat-producing isotopes being potassium-40, uranium-238, uranium-235, and thorium-232 (1).

Brief History of Geothermal

Geothermal energy has been harnessed for centuries. Ancient civilizations first utilized hot springs for health, as they are a natural source of heated water, and the water located in the hot springs can contain lots of minerals that were thought to be beneficial for health. Geothermal energy has also long been used in many places for cooking and heating. The production of geothermal power has been increasing worldwide during the last decades. The pressure to diversify energy sources away from fossil fuels has lead to the development and increased use of alternate forms of energy such as solar power, wind power, and geothermal power.

Geothermal energy is a source of electricity generation worldwide. Currently geothermal power supplies energy needs in more than 24 countries and most of the energy needs in Iceland (2, 3). The United States is the world's largest producer of geothermal energy, with a current capacity of 3,093 megawatts (MW). The largest geothermal development in the world is located at the Geysers north of San Francisco, in Sonoma County, California. The second largest producer of geothermal energy is the

Philippines which produces 1,904 mega watts per year. Indonesia is also a primary producer of geothermal energy producing 1,197 mega watts of energy. Like the west coast of the United States, Indonesia and the Philippines are located along the ring of fire making them very suitable countries to harness the potential geothermal energy that lies beneath them. Mexico, Italy, New Zealand, Iceland and Japan follow (4). The total world production is 10,715 MW in 24 countries (5) In the United States geothermal generation is the largest of any other country in the world amounting to more than 3,000 megawatts in eight states with 80% of this capacity in the State of California which derives 5% of its electricity needs from geothermal plants (2). Geothermal power is considered a cost effective, reliable, sustainable, and an environmentally friendly alternative to fossil fuels. Because of its dependence on areas of heat transfer that are accessible from the earth surface geothermal plants have usually been located in the vicinity of tectonic plate boundaries.

Geothermal in the Long Valley Caldera, California

Energy production is site specific. Different biophysical regions in the world are better for certain types of energy than others. For example, desert landscapes offer greater opportunity to harness the full potential of the sun than do forested temperate zones. Wind farms require exposed areas, whether on land or water, such as the Netherlands or the plains of the Midwest. Regions of active volcanic activity are especially suited for the production of geothermal power. In the United States, the west coast is especially productive in geothermal energy because it is a region that contains numerous volcanoes from Alaska through California and Nevada. This area is the eastern portion of what is known as the world's 'Ring of Fire' the western portion being in the eastern coast of Asia.

The Long valley caldera is an active volcanic geological system. It is one of the earth's largest calderas measuring about 17 by 32 kilometers, and almost one kilometer deep. The word caldera comes from the Latin word caldaria which means cooking pot (The term caldera was introduced into the geological vocabulary by German geologist Leopold von Buch in 1815). A caldera is formed when the magma chamber beneath a volcano collapses. This is generally a result of a large volcanic eruption. After the eruption, the magma chamber is unable to support the weight of the volcanic edifice above it and collapses. A ring fracture develops around the edge of the chamber and as the magma empties the center of the chamber begins to collapse along the ring fracture. The chamber can collapse due to multiple eruptions or one large one.

The Long Valley Caldera was formed 760,000 years ago by a catastrophic volcanic eruption. The Long Valley Caldera is a complex and dynamic hydrothermal system that has a wide variety of geological formations that are apparent in the landscape. The relationship between the hydrothermal system and the volcanic and the tectonic processes at work on the valley has contributed to its present characteristics, some of which we observed in our field trip.

The components of the Long Valley Caldera hydrothermal system are hot springs, fumaroles, streams, wells, and precipitation.

Hot springs are springs (flows of ground water that rise to the surface on the earth) that are geothermally heated, that is, water that is heated by the earth's internal temperature. Fumaroles (from the Latin *fumus*, smoke) are steam vents, fissures in the surface of the earth that let out steam and gasses that are produced deep under the ground, usually in association with volcanic activity. Streams are flows of water on the surface that collect water from precipitation and from snow melt runoff.

Mineral deposits are the result of thermal activity and are found on the resurgent dome, at Little Hot Creek springs, Hot Creek Gorge and in other locations near the south and east moat of the caldera.

Hot springs are located primarily in the eastern half of the caldera, at Casa Diablo, Hot Creek Gorge, Little Hot Creek, and along the south side of the Resurgent Dome, where land-surface elevations are lower.1 They discharge into the Hot Springs Gorge, the Little Hot Creek, and the Alkali Lakes Region. On

[1] USGS Hydrologic studoes in Long Valley Caldera, California. http://lvo.wr.usgs.gov/Hydrostudies.html

the western side of the Resurgent dome (at the higher elevations in the valley) there are fumaroles, mineral deposits, and mud pots.

One important characteristic of the hydrothermal system at Long Valley Caldera is the interconnectivity of its parts. The system is recharged primarily by snow-melt from the highlands on the southern and western rims of the caldera. Water from rain and snow melt infiltrates highly porous ground surface travels down to depths of several kilometers where it is heated by hot rock.2 Hydrothermal fluid travels upward and laterally generally from west to south east and east, discharging in Crowley Lake. The water temperature shows a gradient in Long Valley from a high of 220 C near Inyo Craters to 50C near Crowley Lake due to the mixing of thermal with cold water, and due to heat loss.3 What is important about this is that potential contamination in one place in Long Valley Caldera will travel horizontally to other parts of the system.

The history of geothermal production in Long Valley Caldera begins in the 1980s when exploratory wells were drilled in the area to assess potential geothermal power. In 1985 a commercial plant was built at Casa Diablo. Government incentives later on lead to more research and development in the area. Ormat Industries bought the Mammoth Complex in 2010 and currently manages the operations at the plant with plan for future expansion.

Geothermal Power – how it is done

Unlike most energy sources that require heat to be manufactured by humans, geothermal energy utilizes the natural heat of the earth and its tectonic processes. In order to access this energy, wells are drilled into areas below the crust where there are aquifers of already heated water, or steam. As pressure increases the deeper into the earth, water is unable to turn into steam as it is heated because there is so much pressure. As a result, 'superheated water' is produced at very deep depths of the earth.

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[2] ibid
[3] ibid

As wells are drilled into the rock that houses this water, its steam is converted into mechanical energy for utilization.

There are three main types of geothermal plants: direct dry steam, flash, and binary plants. In a direct dry steam plants steam goes directly to a turbine which drives the generator that produces electricity. Flash plants utilize man-made changes in pressure to vaporize the hydrothermal fluid. The fluid is placed in a tank that is held at a much lower pressure than the fluid causing it to vaporize, and this vapor then moves the turbine which then generates the electrical power.

In a binary cycle plant such as the Casa Diablo Ormat plant in the Long Valley Caldera (Mammoth County California), hot water and steam rises through the production well. This is a deep hole that is drilled for the insertion of a pipe that conveys the high-temperature water and steam that is to be pumped from the ground. The hot water and steam are directed to a heat exchanger alongside the working fluid. Fluids that have much lower boiling points than water are used as working fluids. the working fluid to boil at a much lower temperature than the ground water. The vapor produced by the heat exchanger is directed to the turbines which cause it to rotate at high speeds creating energy. The energy produced by the turbine is then transformed in the generator from where it goes to the power lines. After the steam has been used, it is directed to a condenser where it is turned back into water and re-injected back into the ground through the injection well. The water that rose with the steam also gets returned via the re-injection well.

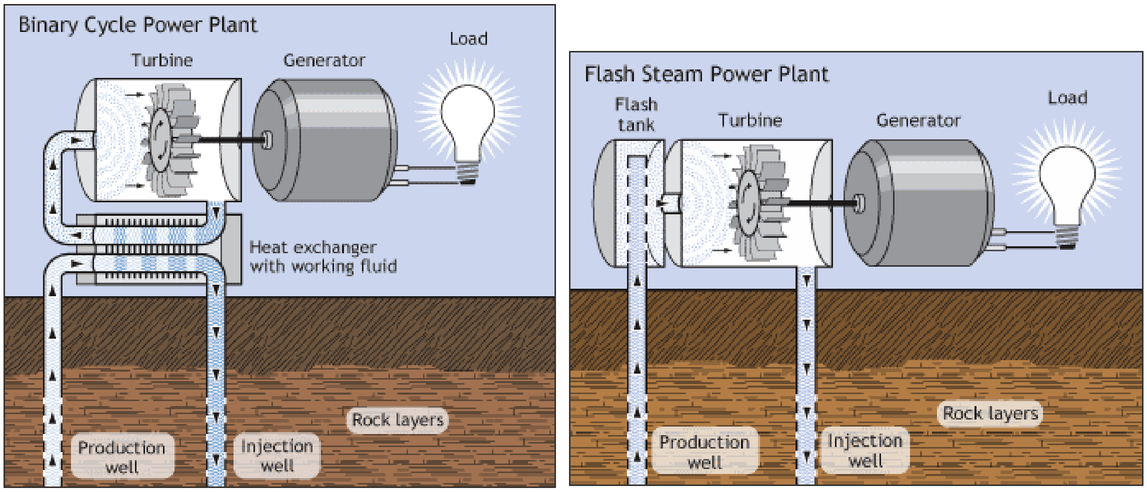

Figure 1 Diagrams of a binary cycle power plant (left) and of a flash steam power plant (right).

Binary plants operate by passing hot water through a heat exchanger with another fluid that has a much lower boiling point (isobutene, pentafluoropropane), the fluid called binary or working fluid then vaporizes which powers the generators and moves the turbines of the plant. Binary plants are more common than steam plants because they can operate at colder temperatures which make finding suitable locations for energy extraction much easier than for steam plants.

Advantages of geothermal energy

As was mentioned in the introduction, geothermal energy is seen as a viable form of energy because it is clean and it is renewable. Another advantage of geothermal energy is that it can be extracted without burning a fossil fuel such as coal, gas or oil. Geothermal fields produce only about one sixth of the carbon dioxide that a natural gas fueled power plant produces. Binary geothermal plants release essentially no emissions. Unlike solar and wind energy, geothermal energy is available constantly. Lastly, geothermal energy is relatively inexpensive; savings from direct use can be as much as 80 percent over fossil fuels.[4]

[4] http://environment.nationalgeographic.com/environment/global-warming/geothermal-profile/)

Environmental impact of a geothermal power plant

The utilization of energy from geothermal wells releases green house gases trapped in the earth core such as carbon dioxide, hydrogen sulfide, methane, and ammonia (6, 7). These emissions are lower than those associated with the use of fossil fuels for which the adoption of geothermal energy sources is considered to have the potential to mitigate global warming and have a favorable impact on the environment (1).

While the environmental effect of geothermal energy generation may be favorable if compared to other sources of energy generation; however it is not insignificant and can cause substantial environmental and human heath deleterious effects. In 1975 Robert Axtmann studied the environmental effects of the Wairakei geothermal plant in New Zealand (7). He concluded that the Wairakei plant discharged approximately 6.5 times as much heat, 5.5 times as much water vapor, and 0.5 times as much sulfur per unit of power produced as would a coal plant at the time in New Zealand. The data also showed contamination of the Waikato River with hydrogen sulfide, carbon dioxide, arsenic, and mercury at concentrations that had adverse but not calamitous effects. It was noted that the plant had been designed in the 1960s when knowledge of the environmental impact of geothermal energy extraction and the hazards of climate change were less understood. It was suggested that the use of techniques which were in development at the time such as reinjection of the hot waste water for liquid-dominated fields would reduce the environmental impact substantially. Ground subsidence was acknowledged as a potential problem but was not observed. More important, the study identified several environmental characteristics unique to geothermal power: first, pollutant formation may be independent of the power production rate; second, effluent pathways may change abruptly generating hazards that have not been anticipated; third, pre-operational testing and random bore holes contribute negatively to the overall impact; and four, waste water may be discharged at temperatures high enough so that utilization of the waste heat becomes both practical and imperative.

These parameters have been taken into consideration in modern geothermal extraction technology for which it is recognized that exploitation of geothermal energy has an impact on the environment but lower than other available sources of energy. The environmental effects of geothermal energy production may then be analyzed from different perspectives which include: first, environmental pollution such as air quality, water quality, underground contamination and chemical or thermal pollution; second adjacent terrain changes such as land subsidence; third, social impacts such as conflicts with cultural traditions and archaeological sites and social-economic disruptions; finally, the consequences of large scale industrial activity such as high noise levels, industrial accidents and the generation of industrial waste.

Environmental pollution

The extent to which geothermal exploitation affects the environment is proportional to the scale of its exploitation (8). In general the environmental effect is more significant in plants with geothermal direct-use applications and potentially greater in the case of conventional back-pressure or condensing power-plants. This is particularly relevant in regards to air quality. Although the consequences of air quality pollution may be high, the probability of such events is considered low for which it is deemed an acceptable risk (9). An analysis of the Argonne National Laboratory concluded that geothermal waters pose a large potential risk to water quality, if released into the environment, due to high concentrations of toxics including antimony, arsenic, lead, and mercury but that the risk of release can be virtually eliminated through proper design and engineering controls (10). None the less, the release of toxic substances, especially hydrogen sulfide remains of concern.

Terrain changes

The use of geothermal energy sources requires the drilling deep holes (boreholes) and the insertion of pipes for pumping high-temperature fluids out from the ground. The rocks that contain high-temperature fluids also contain minerals, which tend to form residues inside the pipes and production equipment. If the rocks contain radionuclides, such as radium, the mineral scale, production sludge, and waste water will contain Technologically-Enhanced, Naturally-Occurring Radioactive Materials (TENORM). The primary radionuclides produced with the geothermal fluids are radium-226 and radium-228. The study of the Argonne National Laboratory has indicated that effective removal of these contaminants may not be feasible in an industrial scale (10). Geothermal power plants usually re-inject the hot water that they remove from the ground back into wells but a small amount of water may evaporate and not be returned to the ground with the potential for ground collapse and sink holes. The withdrawal and re-injection of geothermal fluids also may trigger or increase the frequency of seismic events. However these are micro seismic events that can only be detected by means of instrumentation. The likelihood of a major seismic event is very small never having been documented.

Social impact

Local communities, governments and local organizations have increased awareness of the effect of large scale industrial activity in their environments. The expectation is that there will be a complete disclosure of all the potential impact of the industrial activity. Because of the large number of variables involved in an operation such as geothermal energy extraction, consideration of all the possible consequences of the activity may not be possible which may lead to community opposition to geothermal energy projects. In particularly sensitive areas, the development of geothermal sources may not be feasible. For example, there is ongoing debate whether the development of geothermal energy is even an option in Wildlife Conservation areas in Kenya, in spite of the immense social needs of the community that would be addressed by such industrial activity (11). In addition, there is an increasing conflict of interest between the growth of the tourism industry, population growth and resort community development with their high demands for water and the needs of the geothermal plant. This applies specifically to the Long Valley Caldera Geothermal Area.

Large scale industrial activity

Large scale industrial activity has numerous environmental consequences even when all the variables have been addressed and the negative effects neutralized. Accidents are inevitable in this setting and geothermal energy extraction poses a small but definitive risk of groundwater contamination, especially during the drilling of wells and extraction of hot water or steam. This problem was identified in New Zealand as early as 1975 (7). There are reliable technical solutions that minimize this risk such as re-injecting used water back into the ground through separate wells instead of discharging the used water into surface waters thus preventing underground minerals or pollutants from entering surface waters. Nonetheless, At Casa Diablo plant rare leaks through the heat exchanger have resulted in the presence of trace amount of isobutene in samples taken from wells, hot springs, and fumaroles throughout the caldera. This means that there is high horizontal connectivity that enables the migration of fluids throughout the relatively shallow hydrothermal system in the caldera's south rim (12). Installation of pipelines to transport geothermal fluids and construction of ancillary structures also affect animal and plant life and the landscape. Scenic views may be modified although some times with favorable results such as in Larderello, Italy, where the network of pipelines crisscrossing the countryside and the power-plant cooling towers have become an integral part of the panorama and become a famous tourist attraction.

Conclusions

The thermal energy present in the underground is enormous and broadly available. Geothermal energy production is an effective and reliable source of energy. Its most effective utilization is at the local or regional scale. The implementation of industrial resources for wider distribution of the obtained energy may have substantial environmental and physical consequences but if properly and continuously managed its environmental impact may be minimal. As such is an alternative to fossil fuels worth full consideration.

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