THE USE OF GEOTHERMAL ENERGY IN DESALINATION

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Keywords : Binary fluid cycle, Desalination, Electrodialysis, Feedwater, Flash evaporator, Hydrothermal reservoir, Mechanical vapor compression , Vertical-tube evaporator, Wiped-film evaporator

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1. Introduction

The earth is a huge reservoir of heat which is called geothermal energy. Most of it is buried deep in the magma or too heavily diffused to be felt at the earth's surface. We are aware of it during episodes of volcanic eruptions when molten lava is emitted at the surface. Geysers, hot springs, and fumaroles are other surface displays of geothermal energy.

There are three types of geothermal reservoirs; steam, hot brines, and hot rocks. Steam reservoirs, when available at sufficient pressure and temperature are being used to generate electricity in many countries such as the United States, the former Soviet Union, Italy, Japan, Mexico, New Zealand, Philippines, and Iceland. Steam at low pressure and temperature has been used in district heating, green houses, and process industry.

Hot brine reservoirs at sufficiently high temperature (150°C or higher) can be used to generate electricity and desalt saline waters. Low temperature brines (less than 150°C) can be used to desalt saline water in the process industries, district heating, and agriculture.

Reservoirs dominated by hot rocks require drilling very deep holes into the hot rocks, fracturing them, and then using a working fluid, usually water, to bring the heat content to the surface. Other considerations aside, its practical use depends on the cost of extracting this energy from these deep wells in comparison to the cost of other forms of energy.

2. Historical Perspective

The use of geothermal energy started in early times with hot springs. The description of the general history was given by Koenig (1973). A short description is quoted below:

The early history of geothermal development saw the utilization of thermal springs as baths and health resorts, and the occasional use of thermal waters to heat buildings. Primitive peoples had already used the heat of fumaroles for cooking food and, in arid lands, steam condensate for drinking water. Sulfur deposited from the steam of fumaroles, kaolinitic clays formed by the decomposition of rocks in fumarole zones, and to a lesser extent fumarolic mercury and alum were utilized for centuries. But it was the recovery of boric acid from the fumaroles of Larderello, Italy, that marked the beginning of modern geothermal development. Starting in 1812, fumarolic steam was substituted for wood as a fuel for this operation. Shortly thereafter, the first borings were made for steam at Larderello, both as fuel and to increase the flow of borate source material.

The first experimental generation of electricity from natural steam was undertaken at Larderello in 1904. In 1913 a 250 kW generating station came into service, marking the beginning of continuous generation of geothermal electricity.

After World War I, the concept of geothermal energy was carried to the ends of the world. Experimental borings at Beppu, Japan, began in 1919, and in 1924 a 1 kW generator was installed and operated experimentally. In the United States, test borings were drilled at The Geysers and Niland, California, in the 1920s. Although low-pressure steam was found in abundance, the projects were abandoned for lack of a market for electricity. Holes were drilled at other fumarole areas in the United States in the 1920s and early 1930s, most notably in Yellowstone National Park. A test hole was drilled in Java in 1928, but no development followed.

In Iceland, the exploration of hot-water aquifers by drilling began in 1928 at Reykjavik Municipal District Heating Service. Before 1940, hot-water wells had been drilled for heating purposes at Rotorua, New Zealand. In that year a great many wells were drilled for domestic use in Rotorua and in towns south of Lake Taupo.

World War II disrupted traditional patterns of living; in the reconstruction of war-devastated economies, attention focused anew on geothermal energy. This was especially true in Italy, Japan, and New Zealand: all three were short of fossil fuels for power generation, and generation and transmission facilities had been largely destroyed in Italy and Japan.

Worldwide status of geothermal resources development can be found in Koenig (1973) and DiPippo (1980).

In the late 1960s shortage of fossil fuel in the United States was filled by importation of oil from other countries. Research into the development and use of renewable energy (solar and geothermal) started in the early 1950s. In 1972, there was a special session on geothermal energy at the American Nuclear Society Annual Meeting, June 19-20, at Las Vegas, Nevada. Several experts in the field presented papers that were published in a book entitled *Geothermal Energy* (Kruger and Otto 1973).

After the energy crisis in 1973, the Department of Energy in the United States funded several research and development projects on geothermal energy. Most of the research on the development into geothermal utilization was directed to the generation of electricity. The results were published by the US Department of Energy in a large volume entitled *Sourcebook on the Production of Electricity from Geothermal Energy* (Kestin 1980).

Due to the fall of world oil prices interest in further funding by the Department of Energy subsided and most of the research and testing was discontinued in the late 1980s. To our knowledge no large scale desalination plants driven by geothermal energy as the main source of energy were ever built.

3. Heat Transfer from Geothermal Reservoirs

Heat transfer from inside the earth is controlled principally by heat conduction through solid rocks, by convective flow in circulating fluids, or by mass transfer in magma. Heat transfer in magma affects hydrothermal convection and conduction through rocks.

In areas dominated by conduction through rocks without hydrothermal convective disturbance, the heat flow is relatively constant. The heat flow rate depends on the conductivity of rocks, their porosity, and fluid content in their pores. As a consequence, the temperature gradient is a function of the thermal conductivity of the rocks. Figure 1 shows the temperature gradient for two cases, A and B. Case A, represented by the straight line A, holds for uniform distribution of rocks with constant thermal conductivity and Case B, represented by the broken line B, is for the case of different layers of rocks with different thermal conductivities. The average worldwide heat flow is reported to be about 1.5×10^{-6} cal cm^{-2} s^{-1}(Lee and Ueda 1965, Sass 1971). This is about 0.03 per cent of average solar energy falling on the earth surface, assuming an average solar energy of 4.34×10^{-6} cal m^{-2} day^{-1}.

Heat transfer by hydrothermal convection is a function of the size of the fluid reservoir and its location. Ideally, the temperature in the reservoir is a function of its location below the surface of the earth. Figure 2 is a schematic representation of temperature gradient in such an ideal system. The temperature at the earth's surface is the prevailing ambient temperature. The temperature gradient below the surface assumes that the temperature is at the fluid saturation temperature corresponding to the hydrostatic pressure at the depth below the surface. In such an ideal system, the temperature is constant with depth and then starts to increase below the reservoir causing heat transfer from the hot rock to the reservoir to supply the heat transfer from the reservoir to the earth's surface.

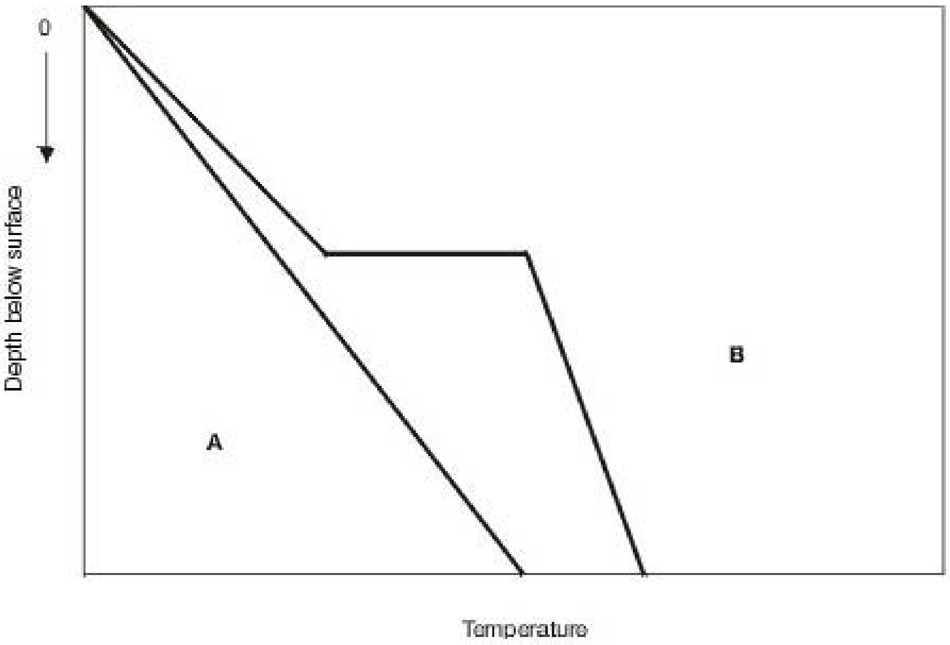

Figure 1. Temperature as a function of depth below the earth surface. Line A shows the temperature profile for constant thermal conductivity and Line B shows the effects of the thermal conductivity of the rocks for three different regions.

Hot water systems have liquid water as the continuous medium pressure controlling fluid. At the bottom of the reservoir heat is extracted from the hot rocks raising the water temperature causing this layer to rise to the top of the reservoir with the layer above the bottom layer to sink down to the bottom repeating the cycle. The continuity of liquid phase in the reservoir can be inferred from measured pressure distribution as a function of depth and from soluble salts of low vapor pressure such as Na, k, Ca, Mg, El, SO_4, HCO_3, and SiO_2 (White 1973).

In water-dominated reservoirs cool rainwater percolates underground from large areas (thousands of square kilometers), and then downward to the reservoir. Here, it is mixed with the water in the reservoir to be heated to the temperature in the reservoir. If the rocks are porous, the heated water rises rapidly to the surface of the reservoir where it is dissipated in the rocks. If the rocks are not porous or only slightly porous with few interconnecting pores, the heat is stored as thermal energy in the reservoir. Figure 3 is a schematic representation of such systems.

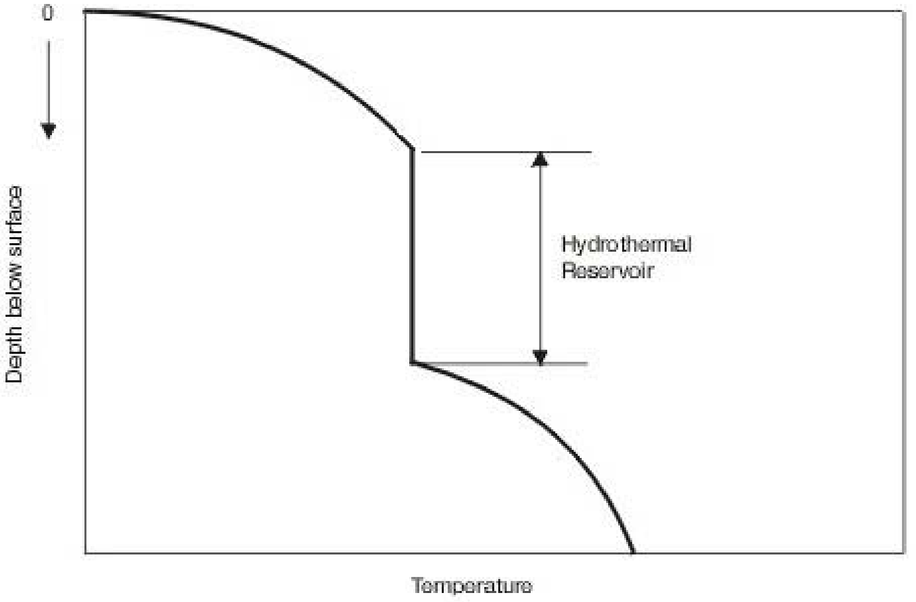

Figure 2. Temperature as a function of depth below the surface for a hydrothermal reservoir. Temperature is controlled by pressure gradient until it reaches the reservoir where it stays constant until it reaches the bottom of the reservoir and then starts to increase with depth.

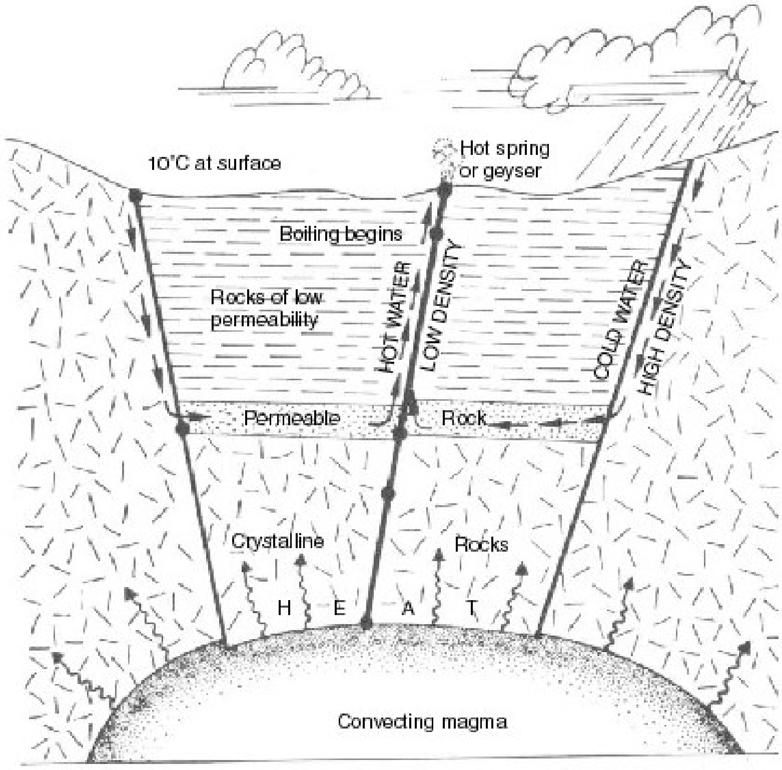

Figure 3. Schematic representation of a high temperature hydrothermal reservoir

Water-vapor dominated reservoirs, also called dry steam reservoirs, produce dry or superheated steam with no associated liquid. Such reservoirs exist in many parts of the world. The best known are those at Laradello, Italy and the Geysers in California. These systems have been used exclusively to generate electricity with conventional turbogenerators, and condensers. Modifications are made to control the presence of corrosive condensable corrosive gases such as H_2S, $NH_{4,}$ and others.

An excellent detailed discussion of the geothermal reservoirs can be found in White (1973).

4. Geothermal Energy Utilization

Geothermal energy can be used in many applications. Its use will depend on the quantity, quality, and cost of the available energy. Low temperature sources (below 150°C), can be used in heating, green houses, desalination, and some industrial applications. Higher temperature sources (above 150°C) can be used for the production of power, chemical processes, desalination, and a combination of these processes. The type of energy, dry steam or hot water, can play a very important part in its use. Low temperature hot water resources have been used for green houses, heating, and some industrial applications while high temperature water resources have been tested for power generation and desalination. This section discusses the role of geothermal energy in desalination.

Desalination of saline waters requires energy, saline water, capital to purchase equipment, and markets for the product water. The use of geothermal energy to desalt saline water will depend on its competitiveness with other sources of energy. The locations of the geothermal resources and the saline water resources play a very important role in selecting the desalination process as well as the cost of energy itself. If the two resources are located a relatively long distance apart, desalting processes that require electrical energy such as reverse osmosis, electrodialysis, and mechanical vapor compression distillation could be the preferred option. If the two locations are close, distillation processes such as multistage flash distillation and multieffect distillation should be considered provided that the net cost of product water is lower than that resulting from the use of the other processes.

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