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History of International Geothermal Power Plants and Geothermal Projects in Germany

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1. INTRODUCTION

With increasing concerns of global warming, green energy sources are becoming more important. The development of geothermal energy applications as a part of Germany's renewable energy portfolio is a multidimensional process with fast growing improvements.

Information regarding geothermal energy applications and actual improvements is given in this paper. Geothermal basic principles needed for application oriented improvements are shown. Geological, hydrogeological and geothermal parameters and future methods of their determination are discussed.

On the basis of these principles, the geothermal aspects of German reference building projects (outstanding shallow geothermal projects) and the latest German geothermal power plants (outstanding deep geothermal projects) are discribed.

2. GEOTHERMAL BASICS

Geothermal energy is energy stored below earth's surface. The word geothermal is derived from the Greek words geo (earth) and thermos (heat), and combining these two meanings yields "earth heat".

Although geothermal energy is one of the youngest types of renewable energy, it is certainly auspicious. While other renewable energy sources depend on the sun, geothermal energy originates in the earth's interior. This underground heat generation is caused mostly by the radioactive decay of persistent isotopes. On average, the temperature increases 3°C every 100 m of depth. This increase in temperature with depth is called the geothermal gradient. Therefore, 99 percent of Earth is hotter than 1.000°C, while 99 percent of the remaining 1 percent is even hotter than 100°C. At depths of about 1 kilometer, temperatures of 35 – 40°C can be achieved. In areas of geological anomalies, such as the Oberrheintalgraben or the Red Sea, geothermal gradients of about 6°C / 100 m can be found, which allows economically viable use of deep geothermal systems.

This vast geothermal energy reservoir can be exploited with the aid of suitable methods. Therefore, the assignment of geothermal engineers is to explore these areas and develop them for use to cool / heat buildings and generate electricity.

In Germany, no high-enthalpy reservoirs exist. To use the given low-enthalpy potential and generate geothermal power efficiently, technological improvements must be made. For this reason, research programs and pilot projects are already being performed. Outstanding shallow and deep geothermal projects in Germany are discussed in this paper to aid in the understanding of geothermal development.

3. DEEP GEOTHERMAL SYSTEMS

Deep geothermal systems depend primary on the quality of the geological source. Geological reservoirs of high geothermal quality are called high enthalpy reservoirs. The locations of these high enthalpy reservoirs correspond mainly to the Ring of Fire, the zone of frequent earthquakes and volcanic eruptions bordering the Pacific Ocean. The risk of failure of high enthalpy geothermal projects in this zone is very low. The risk of failure increases with geological uncertainty.

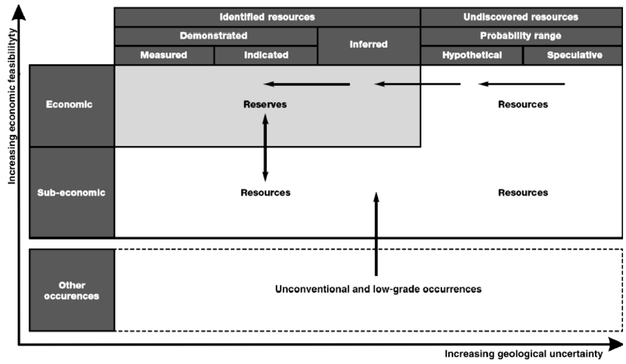

Figure 1: McKelvey-diagram for classification of resources

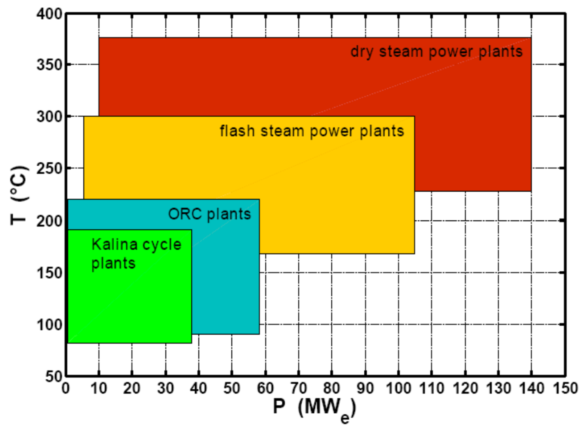

Figure 2: Types of geothermal power plants, Clauser (2009)

The first deep geothermal systems (geothermal power plants) were developed in high enthalpy reservoirs. The geothermal gradient in these reservoirs were outstandingly high, such that natural steam (dry or wet) could be used directly in primary power plants. Therefore, the first geothermal power plants in the world were dry steam and flash steam power plants.

Most countries in the world, including Germany, have no high-enthalpy reservoirs within their territory. To generate geothermal power, binary power plants must be installed. In these power plants, a binary fluid is evaporated and routed to a steam engine in a binary cycle. These systems are named Organic Rankine Cycle (ORC) or Kalina Cycle.

To provide perspective on the development of German geothermal power plants, the history of international geothermal power plants is described. A summarized time line of international and national geothermal power plants is provided in Figure 3.

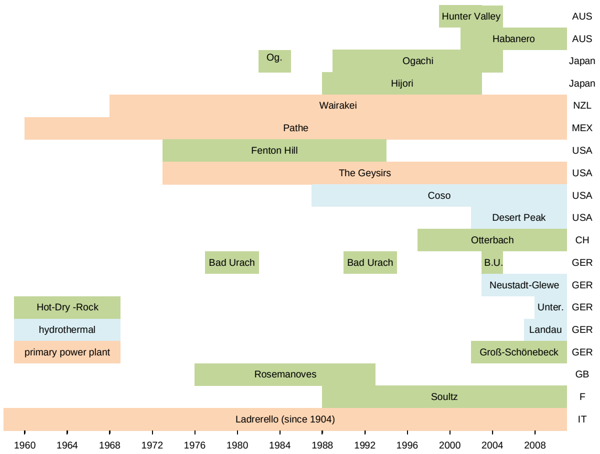

Figure 3: History of geothermal power plants

3.1 International Deep Geothermal Systems

Larderello

The first energetic use of deep geothermal energy sources was developed in Larderello, Italy in 1827. At first, the energy of a high-enthalpy dry steam source was only used for chemical reactions.

Figure 4: Larderello, Italy in 1904

The first geothermal electricity production in the world was performed in Larderello in 1904, although it was only enough to light 5 electric bulbs. In the year 1915, the geothermal operation at Larderello reached an electrical output of 5 MW. Currently, 545 MW of electricity are produced in the geothermal power plant in Larderello.

Figure 5: Larderello, Italy in present day

Wairakei

The second geothermal power plant in the world was developed in 1958 in Wairakei, New Zealand. 54 production wells with an average depth of 800 m produce wet steam at about 250°C in a high-enthalpy reservoir. Electricity is produced there using a triple flash generator. Due to the high temperature of its fluid, the power plant is able to produce about 1,550 GWh of geothermal electricity per year.

Figure 6: Wairakei, New Zealand

The first two hydrothermal power plants were followed by the pilot project in Pathe, Mexico in 1959 and by “The Geysers” project in the USA in 1960.

The Geysers

“The Geysers” geothermal power plant produces about 888 MW of electricity from a natural source of hot dry steam. A photograph of this power plant is shown in Figure 7.

All four of the earliest geothermal power plants generate their power from a natural hydrothermal high-enthalpy source.

The first uses of a geothermal power generation without a natural hydrothermal steam source, called hot-dry-rock (HDR) systems, were developed in 1973. The general possibility of geothermal power production without a natural hydrothermal source was first investigated by scientists at the National Laboratories in Fenton Hill, New Mexico. Although they were not able to reach their goal of of a 50 – 100 l/s production flow, the general possibility of electricity production from HDR systems was proven.

Figure 7: The Geysers, USA

3.2 German Deep Geothermal Systems

Neustadt-Glewe

The first geothermal power plant in Germany was developed in Neustatdt-Glewe in 2003.

Neustadt-Glewe is not located in a high-enthalpy region or a geological hot spot. At this site, water with a temperature of 98°C is pumped from a production well with a depth of 2,200 m.

Currently, the geothermal power plant in Neustadt-Glewe has an output of up to 230 kW. This plant demonstrates successful geothermal power production from 98°C fluid.

Landau

The ORC power plant Landau was developed in 2007. With its low-enthalpy temperature of 160°C, about 3 MW_{el} are produced.

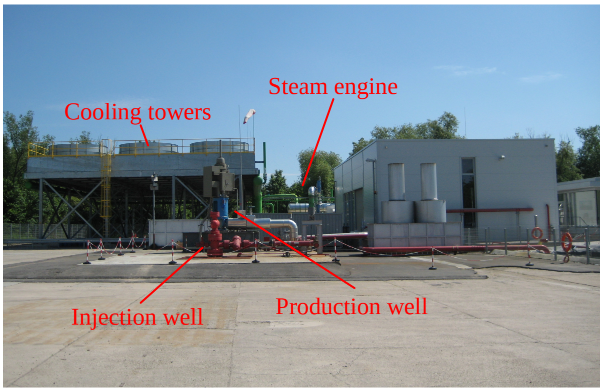

Figure 8: Geothermal power plant Landau

Landau is located in the geological anomaly zone called Oberrheintalgraben. Because of this anomaly, there is a geothermal gradient of about 4.7°C/100m, leading to a bottom hole temperature of 160°C at a depth of about 3,300 m. The geothermal power plant in Landau was the first profitable geothermal power plant in Germany.

Groß-Schönebeck

Groß-Schönebeck is located in the northeastern region of Berlin. A geothermal research center was built upon a former site of petroleum gas drilling by the GeoForschungsZentrum Potsdam.

The GeoForschungsZentrum Potsdam, Germany's National Research Center for Geosciences, is working on making geothermal energy sources in the lowlands of northern Germany suitable for electricity generation. New procedures of tapping deep sandstone are being developed, particularly for use in a 4,300 m deep borehole formerly used for petroleum and natural gas. The aborted drilling was reactivated in 2000 and deepened to its final depth of 4,309 m. A second borehole was drilled at the beginning of May 2006, and stimulation techniques were tested and performed across the two boreholes.

The geological conditions in Groß-Schönebeck correspond to most European low-enthalpy regions. Therefore, Groß-Schönebeck was predestined for developing stimulation methods for suitable geothermal power generation in low-enthalpy regions with geological conditions similar to those in most of Europe.

At the site of Groß-Schönebeck, a research program for hot-dry-rock (HDR) geothermal power plants was initiated. In addition to stimulation methods, the sustainability and the long-term value of geothermal reservoirs were researched and improved.

Unterhaching

The Kalina-cycle power plant Unterhaching was developed supported by national universities and government (state-aided) organizations. Using Kalina-cylce technology, water at 120°C from an aquifer with a depth of 3,500 m is used to produce about 4 MW_{el} and 30 MW_{th}.

Unterhaching is located near Munich. The geological, hydrogeological and geothermal conditions of Munich are quiet different from those of the aforementioned projects near Berlin (Groß-Schönebeck), northern Germany (Neustadt-Glewe) and the Oberrheingraben (Landau). In the case of the geothermal power plant located in Unterhaching, the main geologically homogeneous regions suitable for geothermal use are being investigated and researched in pilot projects.

4. SHALLOW GEOTHERMAL SYSTEMS

Shallow geothermal systems are well probed in different projects in Germany for the heating and cooling buildings. Examples of different systems are open groundwater usage (WestendDuo, Frankfurt), groundwater heat storage (Reichstag, Berlin), a field of borehole heat exchangers (municipal building, Frankfurt), and earth affected structures (Skyper, Frankfurt) integrated with the concepts of construction and heating/cooling.

The shallow geothermal systems used for the heating and cooling of German reference buildings are pointed out in the following to explain the status quo of shallow geothermal applications.

4.1 WestendDuo, Frankfurt

The heating and cooling of the high-rise reference building WestendDuo in Frankfurt is supported by geothermal energy. Groundwater at a temperature of about 18°C is produced by two wells at a flow rate of 43 m^3/h. The temperature level of the withdrawn fluid is raised by a heat pump, used, and reinjected into the ground in three injection wells.

The system is defined as an open loop system, because both the energy of the ground and the groundwater itself are extracted. The concept of the open loop system is shown in Figure 9.

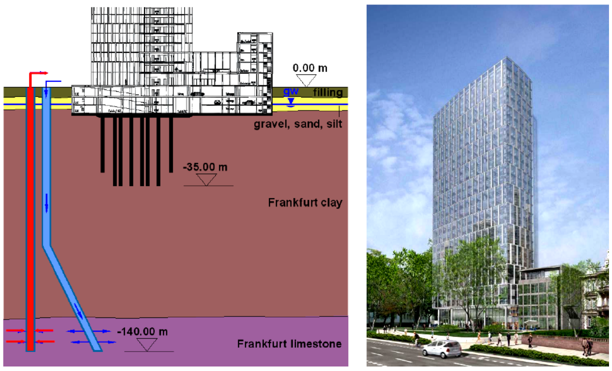

Figure 9: Heating/cooling system of WestendDuo, Frankfurt

4.2 Reichstag, Berlin

Another German reference building that uses geothermal energy is the Reichstag building in Berlin. The Reichstag has been the seat of the German House of Parliament since 1995. The climate concept is based on a geothermal groundwater heat storage system. This groundwater heat storage system is used to heat and cool the innovative building.

In the summer, excessive heat is carried by fluid at 70°C into a subsoil heat reservoir at a depth of 300 m. During periods of peak demand in winter, the stored heat is able to be recovered. Even then, the regained water temperature is up to 65°C. Additionally, a second groundwater reservoir at a depth of about 50 m is used for storage of lower temperatures (“cold storage”).

An open loop system is also used in the Reichstag in Berlin, as shown in Figure 10.

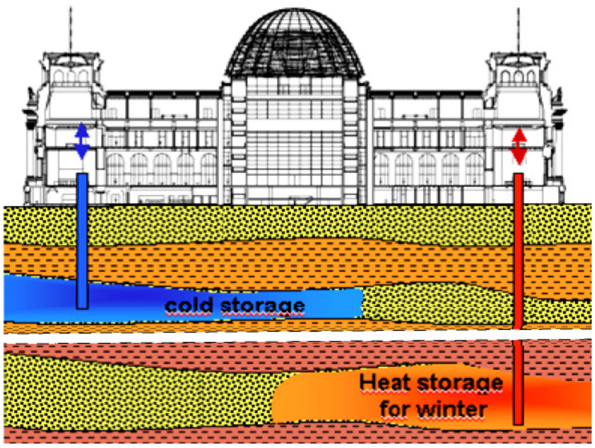

Figure 10: Heating/cooling system of Reichstag, Berlin

4.3 Municipal building, Frankfurt

The municipal building in Frankfurt was built in 2008. Its heating and cooling is supported by geothermal energy. 112 borehole heat exchangers (BHE) are used to generate 600 kW of heating and cooling power.

These BHEs are installed with a length of 85 m each, corresponding to a total absorber length of about 9,500 m. Inside the BHEs, a fluid is run through high-density polyethylene (HDPE) tubes, gathering the heat of the surrounding ground via conduction. This shallow geothermal system of borehole heat exchangers is defined as a closed loop system, because only heat is extracted (no fluid). The geothermal system used for the heating and cooling of the municipal building, Frankfurt is shown in Figure 11.

Figure 11: Heating/cooling system of municipal building, Frankfurt

4.4 Skyper, Frankfurt

The high-rise Skyper building is located in Frankfurt. The 151 m high office building was built in 2004 and is supported by earth affected structures (energy piles).

HDPE tubes with lengths up to 35 m were installed in the foundation piles. 30 km of HDPE tubes support the energy system in the building, which corresponds to a cooling power of 160 kW, a heating power of 300 kW, and a CO_2 reduction of about 90 tons per year.

The heating and cooling of the Skyper building with energy piles is illustrated in Figure 12.

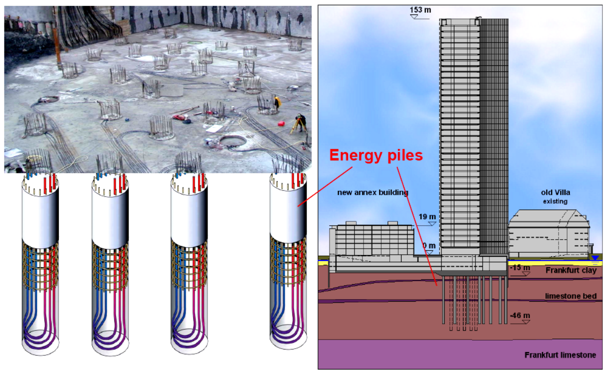

Figure 12: Climate concept Skyper, Frankfurt

5. CONCLUSION

Different geothermal research projects were developed in Germany (Neustadt-Glewe, Landau, Groß-Schönebeck and Unterhaching). Using the experiences gathered in these research projects a production of geothermal power in low-enthalpie regions could be possible all over the world.

Baseload electricity could be produced in decentralized geothermal power plants all over the world.

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