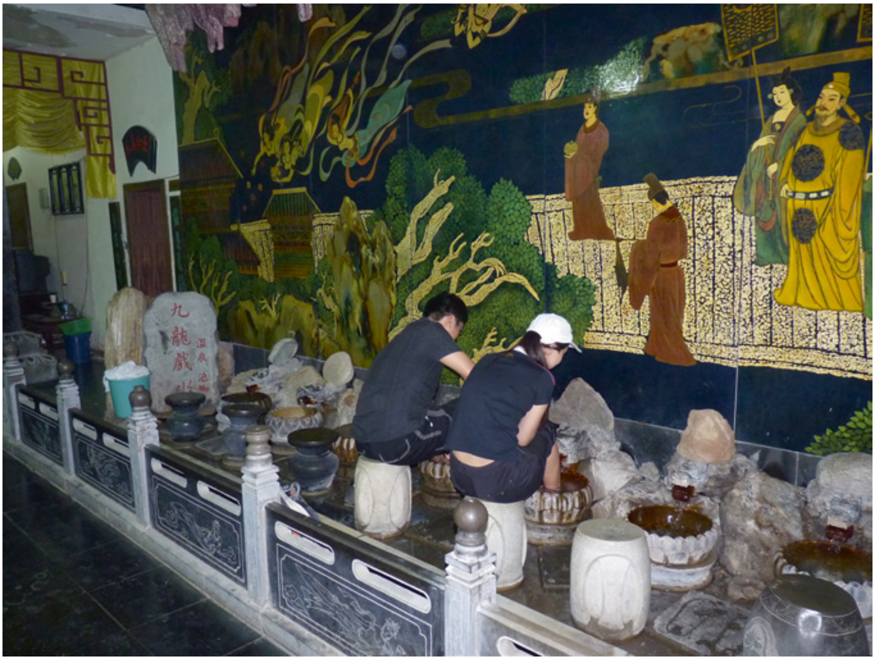
Chapter 2
History of Geothermal Energy Use



Huaqin Hot Springs near Xi'an, China

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Geothermal energy, heat from the interior of the planet Earth, has been utilized by mankind since its existence. Hot springs and hot pools have been used for bathing and health treatment, but also for cooking or heating. The resource has also been used for producing salts from hot brines. For the early man the Earth internal heat and hot springs had religious and mythical connotation meaning. They were the places of the Gods, represented Gods or were endowed with divine powers. In many modern societies bathing in hot spring spas has still preserved the meaning of a divine ceremony.

Natural springs, where water emerges from the underground, have been symbols of life and power in all religions and civilizations. The mythical significance of springs producing hot and highly mineralized water from which minerals precipitate and form sinter, crusts and unusual mineral deposits was and still is immense.

Thermal springs had a religious and social function from early on. Godly healing power has been attributed to hot springs, where gods were near. Thermal springs and spas were centers of cultural and civilization development. In the Roman Empire, the middle Chinese Dynasties and the Ottoman Empires spas have been centers of balneological use of hot springs, where physical health and hygiene (modern term: wellness) have been combined with cultural and political conversation and progress of the time.

Natural hot springs (onsen) are numerous and highly popular across Japan. Every region of the country has its share of hot springs and resort towns, which come with them. There are many types of hot springs, distinguished by the minerals dissolved in the water. Different minerals provide different health benefits and all hot springs are supposed to have a relaxing effect on your body and mind. Hot spring baths come in many varieties, indoors and outdoors, gender separated and mixed, developed and undeveloped. Many hot spring baths belong to a ryokan, while others are public bath houses. An overnight stay at a hot spring ryokan is a highly recommended experience to any visitor of Japan.

Hot springs have been (and still can be) regarded as godly messengers of the immense energies stored in the subsurface of planet Earth.

2.1 Early Utilization of Geothermal Energy

Archeological finds prove that North American Indians utilized geothermal springs several thousands of years ago. Hot springs of South Dakota (USA) have been battlegrounds among Sioux and Cheyenne tribes. Healing powers from the deep interior of the Earth have been attributed to the hot waters from the springs. A bathtub carved into the rocks at the springs witnesses the use of the waters by the Indians for therapeutical bathing. They also drank hot spring water to cure gastro-intestinal health problems. Later, white settlers started to use the hot springs for balneological purposes commercially. Today, the hot water is utilized for cooling and heating purposes with the assistance of heat pumps. Similar “Indian Hot Springs” are found along Rio Grande in Texas and in Mexico. The natives of North America have also used them for therapeutical purposes and for bathing in rock pools since time immemorial. Several thousand thermal springs are known in the USA.

Fig. 2.1 Fishing Cone Geyser in Yellowstone Lake (Yellowstone National Park, USA), (Photograph: US gov)

A peculiarity is Fishing Cone Geyser submerged in water near the Shore of Yellowstone Lake, which has been used for cooking fish by fishermen (Fig. 2.1). The small crater had been above water surface of the lake for some time and the fishermen held the rods with the still flouncing fish for cooking into the boiling and steaming small crater either from the boat or from the beach. Today Fishing Cone Geyser submerged in the lake water and the hot water eruptions stopped.

Historical written documents by the Romans, Japanese, Turks, Icelander, also from Maori in New Zealand describe the occurrence and utilization of hot springs for cooking, bathing and house heating. About 2,000 years ago, bathing and treatment centers have been erected at the hot springs Huaquingchi and Ziaotangshan near Beijing in China.

About 3,000 years ago, gods of Greek civilization have been associated with thermal and mineral waters and their healing power. In the 3rd to the 1st century B.C. Celts worshipped springs with healing power, e.g. the thermal springs of Teplice in Northern Bohemia. Bath in Southern England is associated with the cure of king Bladud, the father of King Lear, from leprosy in 863 B.C. Bath are the waters of Sul, the god of wisdom.

The Celts and then particularly the Romans demonstrably extensively utilized thermal springs in central Europe. Already more than 2,000 years ago, the Romans heated their baths with geothermal energy. It is proven that the Romans settled preferably in the vicinity of thermal springs from 2nd century B.C. Examples

Fig. 2.2 Ruins of the Roman bathing facility at the thermal springs of Badenweiler in the Rhine rift valley (southern Germany)

are Aix-en-Provence (Aquae Sextiae), Bagnière de Luchon in the Pyrenees, Wiesbaden Germany (Aquae Mattiacorum), Baden–Baden Germany (Aquae Aureliae), Badenweiler (Aqua Villae) (Fig. 2.2) and many other places. No other epoch of the western civilization celebrated bathing and bathing culture with more delight than the classic Roman period. "Sanus per aquam" healthiness through water was the motto of the Romans. Bathing was the most important pastime of the Romans. Wellness has been a central aspect of their lifestyle; bathing was a feast for all senses. The bath was the place for social gathering, used for business affairs and for sports.

In Roman times established spas offered regular bathing programs, which were fundamentally related to the believe in gods that were responsible for health. Liable for the success of a treatment were primarily the gods of the local springs such the Celtic-Roman god Apollo-Grannus and not so much the well-trained balneologists. In Roman spas cured patients donated sanctified platelets to express gratitude for the celestial accomplishment.

The hot springs of Badenweiler in the Black Forest (Germany), as an example, have been used by the Celts (known from coin finds). Shortly after the Roman conquest of the lands East of the Rhine river at the end of the first century A.C. The invaders raised a civil settlement and a bathing house (Fig. 2.2). During Roman times the water must have been significantly warmer than today's 26.4 °C, because the Romans built the large bathing halls without heating systems (Cataldi 1992). Also the mineralization of the water was probably higher than today even in the year 1560 according to the "spa travel guide" (Badenfahrtbüchlein) of

Fig. 2.3 Thermal spa Baden–Baden, Roman soldier spa, underfloor heating system, first geothermal heating system

Georgius Pictorius. After the withdrawal of the Romans the spa sunk into oblivion. It was rediscovered and unearthed in 1784.

The roman settlement Baden–Baden, Aquae Aureliae, in the foothills of northern Black Forest can be traced back to the first century. It developed into an important administrative town during the 2nd and 3rd Century. Aquae Aureliae was a flourishing town in the Roman province Germania Superior. The roman city centered on the curative thermal springs, which were the source of the economic success and importance. The luxury imperial spa built by order of the roman emperor Caracalla is located underneath today's market square of Baden–Baden. The spa was destroyed in the year 260. The distinctly more frugal soldier spa is situated at some distance from the imperial spa. The extremely comfortable roman spas were technically highly sophisticated and very cultivated institutions. The spas were built with a so-called hypocaust system (hypocaustum) of central and underfloor heating, in other words with a geothermal heating system (Fig. 2.3). The Romans used the spas wearing wooden sandals protecting them from the hot floors.

Many of the spas have been abandoned after the retreat of the Romans from large areas of Europe. The early Christians preferred to build the first churches close to curative hot springs that have been used from ancient times. In central

Europe of the Middle Ages thermal springs had such an enormous importance that e.g. Charlemagne (Charles the Great) expanded the imperial seat in Aachen to his palatinate and in the year 794 declared it to his permanent residence. The thermal springs of Aachen have already been used by the Celts and the Romans but have fallen into oblivion for several hundred years. The legend says Charlemagne was on a hunting trip in the vicinity of Aachen, in midst of overgrown remains of Roman times. The horse of the sovereign got stuck in a swamp. Charlemagne realized the sludgy water was hot and that steam emerged from the soil. Charlemagne has re-discovered the hot springs of Aachen.

The thermal spas southeast of Oradea in medieval Transylvania have been established at the hot springs of Peta River. The waters of Peta have later also been used as "defrost liquid" by directing them to the castle moat around the fortress of Oradea to prevent the water from freezing and to maintain the functionality of the moat.

In Chaudes-Aigues in central France, construction of the first district heating system, still functioning today, has been commenced in the 14th century (Lund 2007).

Most of the old roman spas were re-discovered in the 13th and 14th century. The big boom of the European thermal spas, however, started not before the 18th century. The spas developed to meeting places of the nobility, aristocracy and the rising bourgeoisie. The first scientific studies on the therapeutic use of thermal spas and the chemical composition of the waters have been written by the monk Savonarola and by the anatomist Fallopio in the 15th and 16th century.

The first reports from China on thermal springs including therapeutic instructions and farming guides go back as far as the 4th to the 6th century. For example, the diversion of thermal water to the fields for rice crop permits the first harvest already in March and allowed for three harvests in the year. The pharmacologist Li Shizhen has written the first scientific review of mineral and thermal waters in China in the 16th century. In his book, "Compendium of Materia Medica" he classified the waters on the basis of chemical and genetic criteria.

In 1560 Georgius Pictorius published an account of the spas of southern Germany ("Badenfahrtbüchlein") and instructions how to use them. It represents a first balneological treatise. Georgius Pictorius studied medicine at the University of Freiburg and was later regionally well known for his medical essays. He had studied all relevant experts on therapeutical bathing of the Antique and the Middle Ages. In his "Badenfahrtbüchlein" he described all classic spas in southwestern Germany that all are still in use today one by one.

Early experience with geothermal phenomena has also been reported from the mining industry. Agricola realized in 1530 already that the temperature in underground mines increases with depth. The first reported temperature measurements with a thermometer are probably those by De Gensanne in 1740 in a mine near Belfort France. Alexander von Humboldt measured a temperature increase of 3.8 °C per 100 m depth increase in the mining district of Freiberg, Saxsony, in the year 1791. This was the first report on the concept of the geothermal gradient, a fundamental parameter in geothermal energy exploitation. Its existence and variation was rapidly confirmed by data from Central and South-America. In Germany, temperature measurements in deep drill holes up to 1,000 m depth were carried out in the years 1831–1863. A few years later, measurements down to 1,700 m followed. An average temperature increase of 3 °C per 100 m emerged from the rapidly increasing volume of data, which is known today as the normal temperature gradient. The first measurement of the surface heat flow density has been achieved by Benfield (1939).

A surprisingly high temperature of 38.7 °C has been measured at the bottom hole of the 342 m deep drillhole Neuffen in Southern Germany in the year 1839. This corresponds to a geothermal gradient of 9 °C per 100 m. The first large geothermal temperature anomaly had been discovered.

2.2 History of Utilization of Geothermal Energy in the Last 150 years

Using thermal water for energy conversion did not start before the second half of the 19th century related to the rapid development of thermodynamics. Thermodynamics helped to efficiently convert energy from hot steam first in mechanical energy and then into electrical energy with the help of turbines and generators.

The development of geothermal power generation is clearly associated with the Larderello region of Tuscany in northern Italy (Tiwari and Ghosal 2005). Until the early 19th century the thermal springs near Larderello have been used for the production of boron and other substances dissolved in the thermal water. In 1827 Francesco Larderel, the founder of the boron industry, installed the first plant for geothermal energy conversion. One of the hot water ponds has been covered with a brick cupola. The construction was the first low-pressure steam boiler heated naturally with geothermal water. It produced the heat needed to evaporate the boron-rich water for the production of boron and additionally also powered pumps and other machines. The installation saved large amounts of firewood and the deforestation of the region could be brought to an end. In the year 1904 the first electrical power was produced from a geothermal energy source by coupling a steam engine to a generator in Larderello (Fig. 2.4).

When the first Larderello power plant went into operation in 1913 it already had an electrical power of 250 kW. In 1915 the power station had power of 15 MW and was driven by saturated steam. From the year 1931 on, new deep drillholes produced superheated steam for the electrical power plant with a temperature of 200 °C. Superheated steam did not contain constituents that cause corrosion and scale formation in contrast to saturated steam. The installation of heat exchanger systems was therefore not necessary. In 1939 the total installed power of all Larderello power plants was up to 66 MW. The Italian geothermal fields were destroyed at the end of WWII but rebuild after the war. Today 545 MW electrical power is installed at the Larderello plants, 1.6 % of the total electrical energy production in Italy (2010).

Fig. 2.4 Lardarello 1904: The picture shows Principe Piero Ginori-Conti with his apparatus that converted geothermal to electrical energy for the first time in history. The installation had the power to light fife light bulbs (Photograph: Unione Geotermica Italiana 2010)

The Larderello geothermal fields are caused by shallow level igneous intrusions at the convergent plate margin of the Apulian and Eurasian plates beneath Tuscany. Extremely high geothermal gradients result from the shallow magma chambers.

In 1890, early systematic geothermal heat utilization was accomplished in Boise, Idaho, USA by completing a district heating system. This system was copied in 1900 by Klamath Falls, Oregon, USA. Later, in 1926, Klamath Falls started to use a geothermal well to heat greenhouses. The first private homes were geothermally heated from separate wells in Klamath Falls in 1930.

The utilization of thermal water for heating homes and greenhouses started in the Reykjavik, Iceland, on a large scale in the 1920s. The name Reykjavik, steaming bay, was given by the Vikings because of the visibly steaming thermal springs. The first wells were drilled into hot water reservoirs for heating buildings as early as in the middle of the 19th century. Geothermal heating of public buildings and entire city districts followed.

Today, Iceland is clearly number one in utilization of geothermal energy in the world. 79,700 TJ or 53 % of primary energy is supplied by geothermal sources. Geothermal and hydroelectric energy provide 99.9 % of the country's electrical energy demand. Low-enthalpy geothermal fields near Reykjavik supply water with temperatures of up to 150 °C which can be used in house heating systems. More than half of the Iceland's population lives in the area. Geothermal fields provide heat and hot water for 90 % of the Icelandic households. The high-enthalpy fields are located along the active volcanic belt that crosses the island. Typical temperatures are 200 °C, but these waters are highly mineralized and gas-rich and cannot

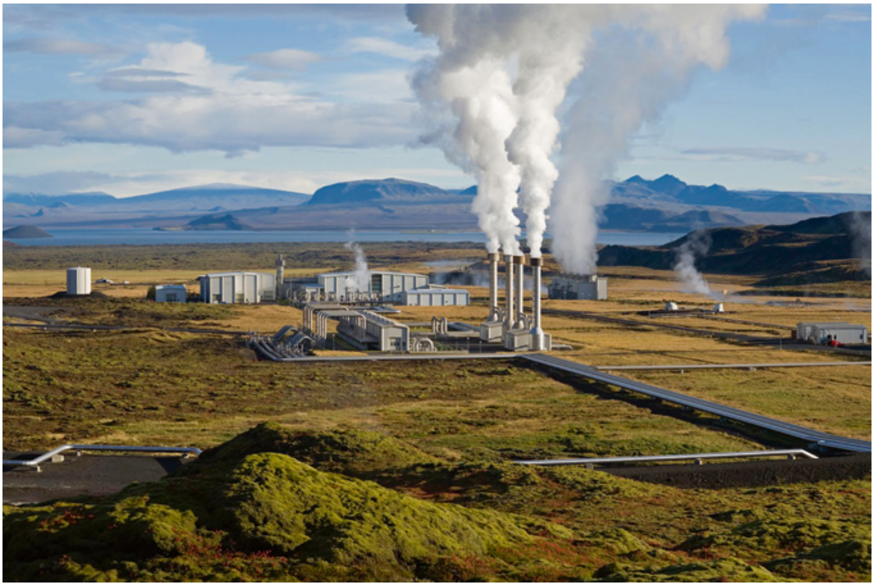

Fig. 2.5 Nesjavellir Power Plant on Iceland; 120 MW electrical power plus 380 MW thermal power from 83 °C water in 2010, reservoir temperatures up to 380 °C (*sources* http://de.academic.ru/dic.nsf/dewiki/1010201 and http://www.or.is/media/PDF/Nesjavellir%20ENS%2007.pdf)

be used directly. The diverse power plants produce typically some 10 MW electrical power in steam turbines. The Nesjavellir plant in the southwest of Iceland is the largest electrical power plant on the island. It produces about 120 MW power. It uses the volcanic heat of the central volcano Hengill as well as the heat from springs and drilled wells (Fig. 2.5). The thermal waters of Iceland are employed in many different branches of the industry.

Following the development in Italy and on Iceland, in 1958 New Zealand erected its first geothermal plant in Wairakei; in 1959 an experimental facility started in Pathe, Mexico, and in 1960 northern California initiated the project The Geysers. Today, The Geysers comprise 21 power stations with a total installed capacity of 750 MW electrical power. It is the largest geothermal installation in the world. The produced electricity is sufficient to supply a city of the size of San Francisco.

However, severe setbacks occurred too. The profitability of geothermal energy production is subject to general economic conditions, such as demand, supply and price of other forms of energy for instance crude oil. Changing laws and environmental regulations may cause increasing efforts and costs (Chap. 10). Greece and Argentina, for instance, shut down existing geothermal installations due to environmental and economic reasons. Germany's deep wells for geothermal installations were drilled in the 1980s of the last century following increased oil and gas prices. The further development of deep geothermal systems came to a halt during the economic crisis and the associated collapse of the oil price. Resumption of geothermal energy projects follows the price of dwindling fossil fuel resources.

In the year 2003 the first electrical energy production from a geothermal source in Germany started in Neustadt-Glewe. 2007 the geothermal wells Landau and 2009 the wells in Bruchsal which were drilled in the 1980s already, started to produce electrical energy.

The earliest documented drilling for ground source heat pump systems in central Europe has been completed in the late summer of 1974 in Schönaich, southern Germany. For retrofitting an existing building (from 1965) with a ground source heat pump as the exclusive heating system five ground loops of 50–55 m depth have been installed with a distance of 4–5 m between the wellbores arranged in a linear array of five coaxial probes with thick-walled steel tubing (60 × 5 mm) and a coaxial plastic hose. The probes were loaded with a water-glycol mixture. Grouting of the annulus with a cement-bentonite suspension, a standard procedure today, had not been carried out at that time. Supply water temperatures in the probes were −3 to −4 °C for peak load periods (continuous outside temperatures of −15 to −20 °C during several weeks); return temperature was about +1 °C. The system was in operation for 30 years. One of the probes failed in 2005 probably because of a corrosion damage. Now the system runs with four probes and an oil-fired boiler.

In 1852, Lord Kelvin has invented the heat pump, a crucial piece of equipment for utilizing near surface geothermal energy. Heinrich Zoelly filed a patent application in 1912 to use a heat pump for extracting heat from the subsurface. The first successful implementation of a ground source heat pump system occurred not before the 1940s. These first ground source heat pumps (GSHP) in Indianapolis, Philadelphia and Toronto had ground collectors that have been emplaced close to the surface. An experimental installation of the Union Electric Company in St. Louis used spiral pipes in 5–7 m deep drill holes as heat exchangers. Other early systems such as in an administrative building in Zurich 1938 and the Equitable Building in Portland in 1948 used river- or groundwater as a heat source, thus they are not utilizing geothermal energy in a strict sense.

The US Department of Energy published in 2010 a comprehensive series of four books downloadable as PDFs from their website on the history of geothermal energy development in the USA in the Geothermal Technologies Program: "A History of Geothermal Research and Development in the United States". The series covers the years 1976–2006. A brief history of geothermal energy in the US can be found at http://www1.eere.energy.gov/geothermal/history.html.

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