Detailed information on energy research

In the Upper Rhine Graben, natural geological thermal deposits can be tapped at comparatively low depths with bore wells. In a Franco-German research project in Alsace, scientists have been researching the process of utilising heat from crystalline rock for years, whereby they have optimised the concept and technology. At the site of the research facility, two power companies opened a new commercial power plant in 2016. The electricity is fed into the French grid. In Germany, around 95% of geothermal resources are also found in deep rock and 5% in natural thermal water layers.

A place in the Upper Rhine Graben with particularly good geological conditions for producing geothermal energy is Soultz-sous-Forêts in Alsace. The temperature prevailing at a depth of 1,000 metres is two and a half times the average for central European countries. This geothermal heat anomaly, which is the largest in central Europe, is caused by high fractured rocks in great depth from which hot, thermal water rise. In the mid-1980s, these conditions provided the impetus for setting up a European research facility for utilising the heat contained in the deep rock, i.e. petrothermal geothermal energy.

The German-French project, in which the European Union was also involved for a period, investigated the scientific and technical bases for petrothermal geothermal energy. In 2016, the two energy suppliers Electricité de Strasbourg (ES) and EnBW Energie Baden-Württemberg AG replaced an old research power plant in Soultz dating from 2008 with a new power plant. It is intended to feed approximately 12 million kWh into the French electricity grid every year. This is sufficient to supply, for example, 3,000 four-person households (at 4,000 kWh/p.a.).
In France, the feed-in tariff for geothermal electricity amounts to 22.19 ct/kWh and is based on the gross output of the power plant generator minus the electricity requirement of the ORC power plant. The power requirement of the production pumps is not taken into account.

The new power plant

In 2015, the two energy suppliers ES and EnBW decided to transform the Soultz geothermal power plant from a research facility into a commercial operation. They renewed the entire power generation plant to enable stable, economical operation. The results obtained during the course of the research phase also considerably help in dealing with corrosive salt water and gaseous thermal waters and in sustainably managing a geothermal reservoir.

The geothermal heat (Fig. 1) is converted using a special power plant process, the Organic Rankine Cycle (ORC). This method can utilise heat at a comparatively low temperature level to generate power. In a geothermal plant, in the heat exchanger the heat from the thermal water is transferred to the isobutane working fluid circulating in the secondary circuit, which thereby evaporates. At this point of the circuit the working fluid is under high pressure. The hot steam is then expanded via a turbine. The working fluid is liquefied again by the air-cooled condenser, and is then once again pressurised by a pump.

The new power plant replaces the former research power plant (2008–2015). Its main focus was to test and optimise components in conjunction with manufacturers. The pilot plant was designed for a wide range of operating conditions to enable it to be used in as many different ways as possible for research purposes. With the step taken towards commercial use, the operating parameters and power plant design were then precisely defined. The new ORC system operates more efficiently than the pilot facility and the power plant entered into regular operation in 2016.

From the depths and back again

Soultz-sous-Forêts is located 50 kilometres north of Strasbourg. Temperatures of about 100 °C, instead of the normally expected 40 °C, prevail here at a depth of 1,000 metres. At a depth of around 1,400 metres, a granite unit begins that, due to the changing geological history of the region, naturally has numerous fractures and fissures.

The aim was to „link“ the natural fractures between the deep wells to form a geological heat exchanger in order to enable the water to circulate in the hot rock. For this purpose, large amounts of water were injected into the rock units with overpressure. As a second method, the researchers tested the use of chemical stimulation, for example with low-concentration acids. In the first step, existing fractures were expanded and then cleaned in the second step. The productivity of the wells increased twenty-fold, mainly owing to hydraulic measures. A permanent connection between the deep wells was successfully established, as has been verified by experiments with tracers. Today, this method is generally referred to as an Enhanced Geothermal System (EGS) because the geological heat exchanger is only made usable through human intervention. As part of a research project concerned with the long-term monitoring of geothermal power plants in Germany (known as ANEMONA for short), investigations of the geothermal reservoir are still being carried out in Soultz.

The power plant currently uses three wells: The hot water from a depth of 5,000 metres is conveyed to the surface at a temperature of approximately 160 °C via the GPK 2 production well. There it flows through a technical heat exchanger and transfers most of the heat to the power plant circuit via an organic working fluid (ORC plant). Subsequently, the water is injected back into the deep reservoir at approximately 70 °C via the GPK 3 and 4 injection wells (Fig. 2). The artificially created geological heat exchanger is situated between the bore wells with a volume of approximately 3 km³. The injected water flows through it, heats up again and can be conveyed again to the surface. Distributing the thermal water to be returned to two injection wells enables the underground pressure ratios to be optimised. No seismic events perceptible on the surface have occurred in Soultz for more than 12 years.

Pumps and deposits

The researchers tested two different pumps in the production wells: a line shaft pump, where the motor is located above ground and the force is...
transmitted by a long shaft to the pump underground, and an electrical submersible pump. In the case of the latter, the pump including the motor is located within the well and operates completely in the hot thermal water. The first submersible pumps, which were not yet specifically designed for geothermal conditions, often failed. This led to prolonged plant stoppages caused by mineral deposits, corrosion, vibrations and engine faults. Optimised pumps were installed from 2011 onwards, resulting in significantly longer operating times. Today a line shaft pump is used for the production. Pumps are used for maintaining the pressure, although in Soultz water would naturally rise in the production well. Owing to the increased operating pressure, the gas remains in solution and the thermal water is in the liquid phase (single-phase flow). This reduces corrosion and the precipitation of minerals.

The thermal water contains dissolved salts, about 100 g/l that mainly comprise sodium chloride, as well as minerals and gases, especially N₂ and CO₂. This makes the water corrosive. Deposits particularly occur on the cold side of the water cycle, i.e. after the heat exchanger. These are mainly sulphides and barytes. The scientists therefore tested the addition of inhibitors to the fluid to slow down or prevent deposits. Thanks to the addition of phosphonic acid, an equilibrium has now been established.

**Timeline:**

1987–1992
Franco-German cooperation agreement signed with the participation of the European Union. Feasibility study.

1993–1997
Two wells (GPK 1 and 2) reach a depth of 3,500 m. By means of hydraulic stimulation, the upper geothermal heat exchanger is created between the two wells.

1998–2005
The GPK 2 well is deepened to 5,000 m and two further wells reach the same depth. A second, lower geothermal heat exchanger is created between these three wells using stimulation measures (Fig. 3). The water temperature at this depth is 203 °C. The underground part is therefore ready for operation.

2006–2010
Scientific research on the geological heat exchangers continues. A geothermal research facility with the ORC process is constructed.

2010–2015
Investigations are carried out at the pilot plant concerned with the continuous plant operation with a focus on environmental impacts, reservoir performance, corrosion and deposits. The initially susceptible pumps are successfully optimised and their service life significantly extended.

2015–2016
The plant operators decide to enter into commercial operation with the renewal of the power plant.

The water is re-circulated with all dissolved substances and gases into the original rock layer at a depth of 5,000 m. Hot water from deep earth layers naturally contains radionuclides, such as radium. These can deposit and accumulate in pipes and components. The use of inhibitors has effectively reduced all deposits, including the radioactive ones. In order to guarantee the safety of employees and visitors at the site, the natural radioactivity is regularly measured at the facility. Occupational health and safety measures ensure that the employees' radiation exposure limit values for individuals are maintained at the facility. The employees' radiation exposure in Soultz caused by natural radioactivity is safely below the value of 1 millisievert for a 12-month period. By way of comparison: The natural exposure to radiation in Germany is between 1 and 10 millisievert per year, depending on the place of residence and lifestyle.
Hydrothermal plant in Bruchsal

In addition to Soultz-sous-Forêts, which is the only petrothermal-based plant worldwide, the geothermal plant in Bruchsal in the German Federal State of Baden-Württemberg is also based on a research project. This uses, however, a thermal water aquifer in red sandstone at a depth between 2,000 and 2,500 metres, which is connected by two wells. The power plant, which has an electrical capacity of 0.55 MW, utilises the Kalina cycle, which uses an ammonia water mixture as the working fluid within a closed circuit.

Extensive scientific investigations relating to the hydrochemistry, gas content of the fluid, deposits on the components and corrosion have been carried out at both plants. The salt content in the fluid is very similar, although the plants are located far apart and use waters from different depths. Both fluids have a high gas content. Under standard conditions, 1.0 litre of gas in Soultz and 1.6 litres of gas in Bruchsal are produced per litre of recovered fluid. More than 90 % by volume consists of carbon dioxide. To ensure that the gas is not released in the above-ground part, the systems operate with an overpressure of 20 bar. During plant operation, gas accumulations have an unfavourable effect because, for example, they impair the heat transfer in the heat exchanger. Therefore in Bruchsal the dissolved gas is separated on the surface, is led via a gas bridge past the power plant, and is then re-mixed with the thermal water. In both plants, the fluid is returned to the original rock unit with all accompanying substances.

Deposits on components and corrosion were a further research focus. Inhibitors were also tested in Bruchsal. In normal operation, however, the plant does not require their deployment because the pressure maintained in the above-ground part is sufficient to effectively prevent precipitation. Other topics included material research and corrosion. The Bruchsal plant has several bypasses in the water circuit. There, durability tests are carried out concerned with the corrosion resistance of components. According to a study conducted in 2011, the levelized cost of energy in the Upper Rhine Graben amounted to between 19 and 36 cents/kWh. In the next few years it is intended to reduce this by 10 cents for new plants through initiating a bundle of measures. These include optimised drilling technology, a greater standardisation of the power plant technology and further improved pumps.

More from BINE Information Service

- Corrosion in geothermal plants. BINE-Projektinfo brochure 06/2012
- Geothermal electricity generation in Soultz-sous-Forêts. BINE-Projektinfo brochure 04/09
- This Projektinfo brochure is available as an online document at www.bine.info under Publications/Projektinfos.

BINE Information Service reports on energy research projects in its brochure series and newsletter. You can subscribe to these free of charge at www.bine.info/abo