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The Geothermal Power Plant Bruchsal

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ABSTRACT

At present, worldwide installed capacity of geothermal power plants amounts to approximately 10 GW. The majority proportion of these plants is located in geologically excellent regions which have steam deposits, as opposed to the sparseness of having geothermal power plants in low enthalpy areas such as the river Rhine rift valley.

In the wake of the first oil price crises in the mid-1980s, two boreholes to supply geothermal energy had been drilled in Bruchsal. The fundamental design was to supply heat energy, however, following the renewable energy act (EEG) came into force at the beginning of 2000, a change was necessary. By now, electricity generation by geothermal power plant was in the focus of all other measures.

During the entire project period, many studies were conducted in Bruchsal. In addition to thermal parameters, hydraulic issues and especially the high mineralization of the fluid were investigated. With salt contents above 100 g/l and with high CO_2 concentration, corrosion and scaling are challenging subjects, particularly for geothermal power plant operation.

In recent years, a power plant with a planned electrical output of 550 kW_{el} was built in the site following the Kalina principle. Currently, first commissioning tests on the thermal water sides are done; electricity production is expected in June 2009. The commissioning and the first operating years will be accompanied with further research. The focuses are on coupled models for the reservoir and the interaction between aquifer and power plant operations.

1. INTRODUCTION

The usage of the geothermal energy has a long tradition with regard to the appliance of the thermal water in spas. The electricity generation from geothermal energy can be dated back to over one hundred years. The first trials took place already in 1904 in Lardarello/Italy (Sanner 1992). The world-wide installed capacity today is about 10 GW_{el} and the geothermal power plant are located in regions where geological conditions for geothermal energy are favourable. In territories with a low enthalpy attribute and with reservoir temperature below 150°C are the installations of such power plants rare (Bertani 2007).

German geothermal power plants are located in Neustadt-Glewe, Unterhaching, Landau and Bruchsal. The total capacity reaches 7 to 8 MW_{el} (figure 1).

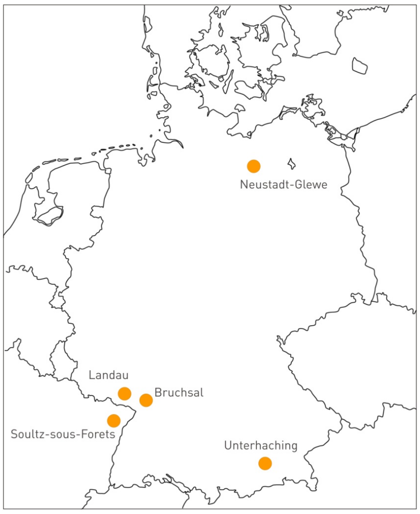

Figure 1: The geothermal power plants in Germany

2. HISTORY OF THE PROJECT

The drilling of a drinking water well in 1979 by an international beverage manufacturer marks the beginning of geothermal activities in Bruchsal. The water captured from this well exhibited an above average high temperature. After extensive land investigations and a longer planning phase, a first thermal water bore hole (GB I) was begun in 1985 at the western edge of Bruchsal. The goal was a pure utilization of heat. This drilling made a find in approximately 2,000 m depth within the range of the Middle Bunter. The temperature of the realized thermal water amounted to over 100°C and first pumping tests achieved a flow rate of 11 litres per second (l/s). Similarly, the first hydraulic chemical investigations indicated a very high mineralization of the water. For environmental protection and technical reasons, drain off of the drilled water is prohibited due to the high salt contents. Consequently, a second thermal water bore hole (GB II) for the reinjection of the lifted water had to be planned. The plan was realized when the GB II was drilled at a distance of 1,5 km and up to a final depth of nearly 2,500 m in 1987. In the same year, the first circulation tests with a flow rate of 15 l/s between the two wells took place.

In the 90's the oil price situation began to ease and from economical considerations it became necessary to put the two bore holes out of service. In connection with the commencement of Renewable Energy Act (EEG) in 2000, the situation changed fundamentally and a new utilization concept of the wells was conceived. Instead of formerly planned pure heat utilization, electricity generation became the focus of the consideration, in view of the compensation system connected with the EEG.

After the reactivation of the wells in 2002/2003, further circulation tests were carried out with a flow rate of 19 l/s and a temperature of 110°C. The boreholes were in technically flawless condition, but the connection pipe between these two wells had to be partially replaced. A result of this circulation test was a new construction concept: the former injection well GB II was redesigned to be the production well and consequently GB I to be for the reinjection of the thermal water into the reservoir. The inducement for the redesign was the depth of GB II, which was considerably more deeply drilled and could provide substantially hotter thermal water. The new utilization concept was supported by a further circulation test, which showed a flow rate of 28.5 l/s and a wellhead temperature of 120 °C.

3. GEOLOGY AND GEOTHERMAL ENERGY AT BRUCHSAL

Bruchsal is located at the eastern edge of Upper Rhine Valley, a NNE-SSW striking extension structure with a length of 300 kilometres and a width of 40 kilometres. The sediments in the Inner of the Valley are compared to the shoulders of the valley about 3,000 meters lowered (figure 2). The Eastern main border fault zone in the area of Bruchsal consists of a whole series of faults, which are echelon-like against each other displaced.

The aquifer of Bruchsal is mainly located in regions of the Middle Bunter, which is very intensive jointed at this location and also traversed by fault zones. Due to the echelon-like character of the fault system, the depth situation of the Middle Bunter in the area Bruchsal increases tendentious toward the west. According to this geological formation, this stone would be found at GB I in a depth of 1,900 meters and in GB II in 2,500 meters. The comparatively shallower aquifer at the GB I shows a temperature at 119°C, while GB II at 131°C. In Germany, the geothermal gradients (temperature increase with the depth) is on average to be 3 K per 100 m. Bruchsal has an over average geothermal gradient of 5.3 K pro 100 m (GB I) and 4.8 K pro 100 m (GB II), is however to be exceeded by elsewhere in the Upper Rhine Valley.

4. RESEARCH

In the course of the fixing of the both drilling locations were a number of seismic profiles shooted. Therefore the geology at this location was very good known before the drilling being started. After completion of GB I and particularly GB II, first water analysis were carried out, which concentrated mainly on hydraulic and fluid chemistry. The different pumping and circulation tests permit an estimation of the transmissivity and the hydraulic permeability. Several borehole logs were made and these enable to the gathering of further information to geothermal condition at the location. Another emphasis was on the hydraulic chemical characterisation of the Bruchsal thermal water.

4.1 Borehole Measurements

In the wells GB I and GB II, different logs were realized. The density measurements showed that a continuously decrease in the wells with according to the depth (figure 3) from 1.08 to 1.02 g/cm^3 (GB I) and in GB II from 1.07 to 1.01 g/cm^3. In contrast the conductivity is reduced from 110 µS/cm near the surface of the water in the well to almost 500 µS/cm at the bottom of the well. Free swing into the wells have a surface of the water at 44.08 meter over NN (GB I) or rather 108.49 meter over NN at GB II.

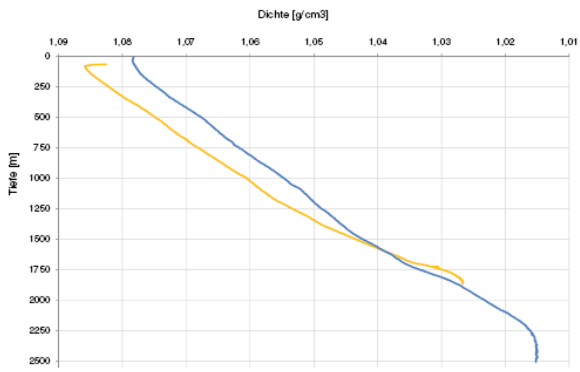

Figure 3: The density [g/cm^3]in dependence of the depth [m]

The measurements of the temperature in the area of the reservoir showed 119.4°C (GB I at 1,865 m) or 134.1°C (GB II at 2,506 m). The average temperature gradients were defined at 0.053 K/m in GB I and 0.048 K/m in GB II (Herzberger 2008). In Germany, such values are to be classified as unusually high (figure 4). For comparable depth in the area of the Upper Rhine Valley, the middle gradients are known to be up to 0.11 K/m. The measurement results in Bruchsal are therefore in the midfield in local comparison (Münch 2005). The consideration of the temperature gradients shows clear decrease for both wells in the area of the reservoir due to the dominating convective heat transfer.

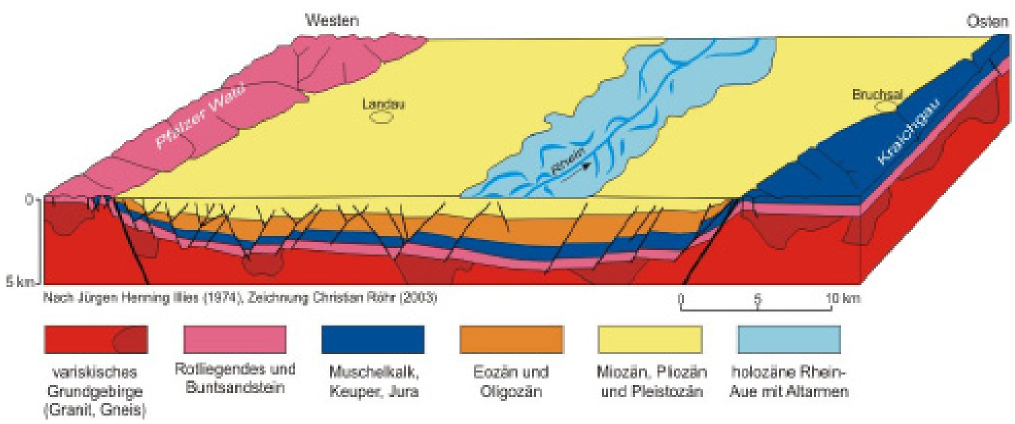

Figure 2: The Upper Rhine Valley and its geological formations

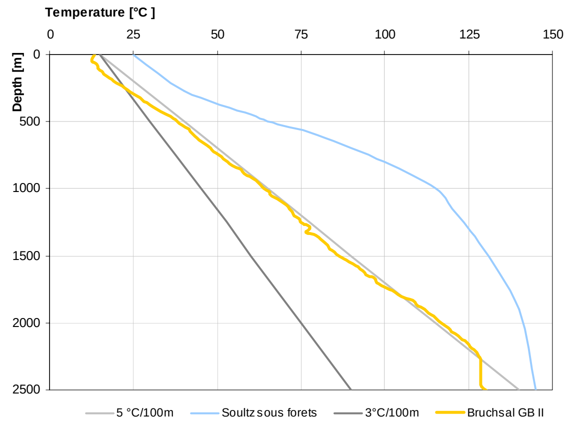

Figure 4: The gradient of temperature from Bruchsal, Soultz-sous-forêts in comparison to the median of Germany.

4.2 Hydrogeology

First pumping tests in Bruchsal were already implemented in the well GB I in 1983. The transmissivity varies over a comparatively large range. According to Joachim et al. (1988), the middle value amounts to $8.1*10^{-5}$ m^2/s. The storage coefficient, taking account of the skin effect, was defined to be $1.3*10^{-6}$. Hydraulically effective edges were not to be determined, are possibly with the discontinued small flow rate at that time also not identifiable. From the investigations at that time for the GB I a permanently realizable flow rate of 15 l/s was prognosticated (Joachim et al. 1988).

Further pumping test were carried out since 1985 and thus after the completion of the well GB II. The flow rate ranges between 6.11 l/s and 22.3 l/s. It was thereby the first time that a pressure sensor at a depth of 2,235 m came into operation. During a pumping test with a flow rate of 11.3 l/s in the GB II the water level in the well GB I reacted with four-hour time delay with a sinking of 90 cm. Joachim et al. (1988) interpreted this as proof of a hydraulic connection between the two wells.

The transmissivity and the storage coefficient were also determined for the well GB II. The values for the transmissivity vary depending upon evaluation procedures between $6.9*10^{-4}$ and $4.0*10^{-3}$ m^2/s. The storage coefficient was defined at $4.8*10^{-6}$. In the comparison of the two wells, GB II is clearly more efficient than GB I.

With the retake of the Bruchsal project at the beginning of 2000 further promotion and reinjection tests were accomplished. A priority goal was it to examine the technical condition of the wells and the feeder line. As is the case for the tests of the 80's, it involves simple circulation tests without any heat extraction of thermal water in a above-ground plant. The promotion pump was hung up in GB II, the well GB I served for the reinjection.

For conceptual as well as technical defects reasons, no measured values could be practically generated for better information to the hydraulic of the aquifer during these attempts. A circulation rate of 28.5 l/s with a temperature of circa 120 °C (figure 5) was indeed maintained over a period of seven weeks. Even in the starting phase of this test, production well GB II came to pressure surges, that were confronted with the opening of the gas release valve. In contrast, in the gaseous phase above the ground-water level in GB I („annular space "), developed quickly a pressure of almost 8 bar, which is increased by approximately 1 bar during the test.

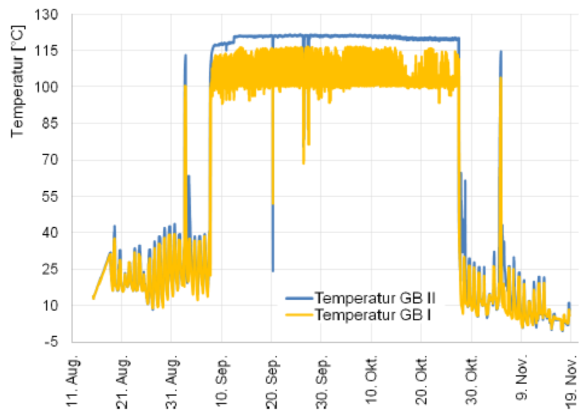

Figure 5: Course of the temperature from the test during seven weeks

4.3 Water Chemistry

At the location Bruchsal were taken several times water tests for chemical analyses. The production of representative samples, which make a characterization possible of the thermal water on reservoir conditions, became very difficult. Nevertheless, the composition of the Bruchsal thermal water with comparatively accuracy was examined in the past.

components [mg/l]	Median 1983-1986	Median 2002-2005
calcium	7581,14	7629,12
magnesium	442,29	374,31
sodium	33317,86	37182,32
chloride	73323,29	75860,00
sulfate	220,43	477,56
hydrogencarbonate	451,00	326,42

Figure 6: Components of the thermal water

The water of Bruchsal is characterized particularly by high components of alkaline/earth alkaline elements like the other thermal waters in the Upper Rhine Valley region. Chloride is the dominating anoin. In addition, high sulphate and hydraulic gene carbonate contents were measured (figure 6 and 7).

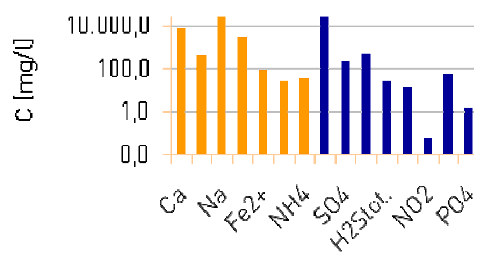

Figure 7: Components of the thermal water. Anions and cations

The mainly components of the heavy metals are plump (Ø 0.5 mg/l) and arsenic (Ø 6 mg/l). The contents of organic substances are not really demonstrative and give no link to an existing hydrocarbon deposit.

The pH-value of the singular measurements ranges between 5.5 and 6 the evaporation residue has a median value about 125.000 mg/l. With regard to the power plant operation, the high mineralization poses a big challenge. In Bruchsal, the calciumcarbonate precipitation primarily dominate (figure 8), while the gypsum/anhydrite, the iron hydroxide and silica minerals are not even important for the practice.

Figure 8: precipitation of calciumcarbonate in the well

By means of the chalk-carbonic acid-balance, the predominating situation of the water chemistry in Bruchsal can be clarified by:

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^-$$

For the typical reservoir situations with regard to the temperature and the pressure the whole calcite is in solution. Through release of pressure, the balance shifts on the left side of the chemical formula and thus remarkable precipitations. This problem can be solved with an appropriate low ph-value, that will be reached with an addition of hydrochloric acid or by aligned pressure maintenance. While on the production side, a pressure of approx. 20 bar is to be adjusted. But at the injection well it is possible to work with a lower pressure, because the water is chilled and the solubility of the CO_2 is thereby better.

4.4 Gas Composition

A special challenge for the stream production arrangement and the thermal water system in Bruchsal is carbon dioxide which is the dominating gas component (figure 9). Under reservoir-typical conditions of temperature and pressure ratios, the carbon dioxide is completely solved in the thermal water. During a pressure relief it comes however to substantial carbonate precipitations, mostly in the form of aragonite. This carbonate develops thick layers in the pipe inside walls of the upper part of the thermal water system in relatively short time, but also – up to a defined depth – in the well itself. On a time scale, this process is rather completed in a time period of a week than of one year.

Another important factor, which has influence on the long time operation of a geothermal plant, is the corrosive character of the thermal water. The choice of suitable materials for the thermal water circulation shows a special challenge, which is examined currently in detail by experts of different research institutes and engineer's offices.

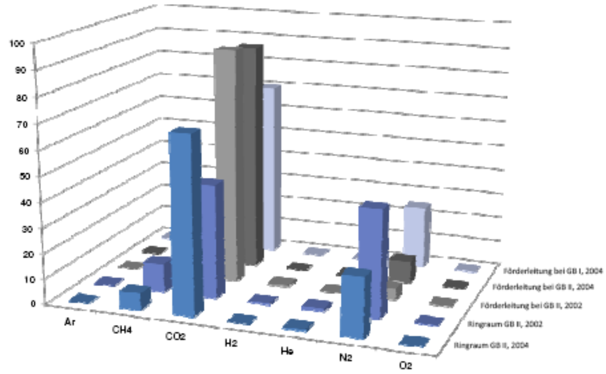

Figure 9: Gas components of the brine of Bruchsal

5. CURRENT RESEACH ACTIVITIES

The project (LOGRO – Long term operation and Optimisation of a Geothermal plant in a jointed porous Reservoir in the Upper Rhine Valley) has the following main focuses:

- Identification and minimization of technical and economic risks of the operation system with integral investigation concept
- Increase of the efficiency of the power plant operating, by operation management and systems engineering in the field of thermal water system and power plant technology, fitted to geo-reservoir behaviour
- Development of servicing and maintenance strategies
- Production of sustainable operating concepts for future projects in the Upper Rhine Valley (sustainable reservoir management and plant operation).

Sustainability in connection with the power production from geo-reservoirs means to shift the time of the thermal breakthrough if possible into the future, in order to maximise in this way the energy efficiency by an optimum use of the reservoir volume and to control the reliably of all relevant technical sub processes at the same time.

The planned research program should contain several main components all together, which concentrate upon the different components of the whole arrangement and the process areas of the underground reservoir:

- Geometry of the geo reservoir, hydraulic conductivity of the permotriassic sediment layers, role of faults
- Geohydraulics of the reservoir, parameterisation, binding of the “Doublette” to the fault zones, effectiveness of the hydraulic connection of both drillings
- Heat transfer and parameterisation
- Process modelling of coupled THMC processes (thermo-hydro-mechanic-chemical)
- Development of fitted operation scenarios
- Power plant operating, including minimisation of precipitations, gas releases, and corrosion

5.1 Tracer-Based Monitoring of THMC-Induced Changes to Reservoir Properties

In order to estimate the thermal life-time of the doublet system, we need to know (A) the fluid residence times under the applied hydraulic regimes, and (B) the density of heat exchange surfaces encountered by the circulating fluids. These two parameters can only be determined by means of tracer tests (fluid spikings) in the field, because they neither correlate with petrophysical properties accessible to direct investigation of rock materials, nor do they produce unambiguous signals in geophysical or hydraulic testings.

The idea of a 'tracer-based monitoring' of long-term changes to reservoir properties is to repeat reservoir spikings (of suitable design) at certain time intervals in order to determine how parameters (A) and (B) have changed as a consequence of operation-induced THMC processes. – For instance, clogging may lead to a reduction of (A); cooling, or 'thermal cracking' may lead to an increase of (B); reservoir stimulation measures generally lead to an increase of (A), but not necessarily to an increase of (B); etc.

To determine (A) fluid residence times, inter-well, forced-dipole spikings shall be conducted: during the normal plant operation process: spent brines being directed to the re-injection well shall be spiked by means of short pulses of concentrated tracer slugs (to be repeated every several years). The tracers used for these spikings must be physico-chemically stable at the time scale of their travel through the reservoir (several years at least) and exhibit as little exchange as possible at fracture surfaces, for their arrival time distribution ('breakthrough curve' BTC) at the production well to reflect (ideally) only advection-dispersion processes in reservoir fractures. For any real tracer however, even if physico-chemically stable an non-sorptive, the effects of dispersion on its BTC will be overlain, to a certain extent, by the effects of matrix diffusion; the latter can be quantified and 'subtracted' from the measured BTC if parameter (B) is known.

To determine (B) the density (area per volume) of heat exchange surfaces, single-well injection-withdrawal, abbreviated as 'push-pull' tests shall be conducted. The reversal of the flow direction reduces (to a certain extent) the effects of advection-dispersion processes, while enhancing the effects of tracer exchange fluxes at fracture surfaces, and thus the influence of parameter (B) on measured tracer BTCs. The tracers used in such tests should exhibit measurable exchange processes at fracture surfaces, like

– sorption, in particular ion exchange (for water-soluble tracers), and/or

– matrix diffusion (for water-soluble tracers and for heat as a tracer).

6. POWER PLANT TECHNIQUE

In the regions which are not characterised by natural steam deposits in the subsoil, the necessary steam for running the turbine is generated in so-called Binary Cycle arrangements. Here the energy of the thermal water will be transferred over a heat exchanger on a secondary circulation loop, where a low temperature evaporating working medium circulates.

Currently organic fluids or an ammonia-water mixture are used as working media in the secondary circulation loop. According to the applied medium, Organic Rankine Cycle (ORC) and Kalina Cycle will be differentiated. Binary Cycle process of the ORC type is a comparatively proven technology. In contrast, the Kalina process, at least theoretically more efficient at rather low temperatures, is realised, up to now, only in the Icelandic Husavyk, in Tokyo and in Unterhaching. Also for Bruchsal (figure 10) a Kalina-type power plant was ordered after the planning and tender phase. The construction of the power plant began in 2007 and finished at the end of 2008. The steam production process was designed for an electric power of 550 kW_{el}. In the future, with an annual operation of approx. 8.000 h, an electric energy of 4.400 MWh should be produced annually.

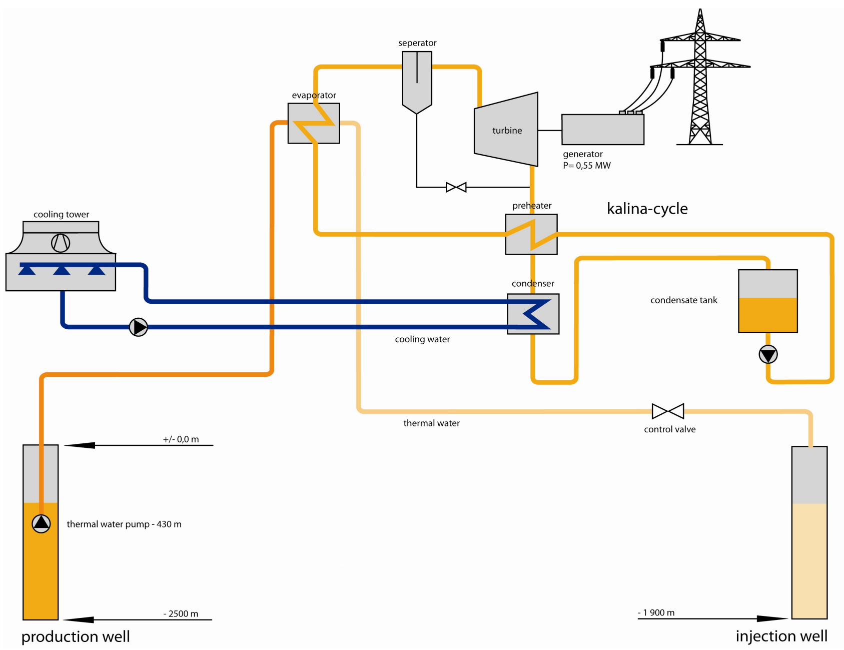

Figure 10: The Kalina –cycle power plant

CONCLUSIONS

The geothermal power plant in Bruchsal is characterized by a project history of over 20 years. The project shows that geothermal energy development depends heavily on the current economic situation, especially on oil prices. Geothermal electricity generation was introduced years later after the EEG came into force.

The geothermal power plant in Bruchsal is a pilot project. The research focuses on hydraulic and hydrochemistry. Corrosion and scaling are the focal points. Several universities as well as private companies participate in the LOGRO project, which is financed by the German Ministry of Environment and EnBW AG. The geothermal power plant will be analyzed in its entirety. The interaction between the power plant and the subsurface will be investigated and optimized.

REFERENCES

Bertani, R. (2007): World Geothermal Generation in 2007. – GHC Bulletin, 19 S., September 2007: S. 9, Klamath Falls (USA).

Bertleff, B.,Joachim, H., Koziorowski, G., Leiber, J., Ohmert, W., Prester, R., Stober, I., Strayle, G., Villinger, E. & Werner, J. (1988): Ergebnisse der Hydrogeothermiebohrungen in Baden-Württemberg. - Jh. geol. Landesamt Baden-Württemberg, 30: 27—116., Freiburg i. Breisgau.

Herzberger, P. (2008): Tiefengeothermisches Projekt Bruchsal; XVII + 200 S., unveröff. Dipl.-Arbeit, Universität Karlsruhe.

Kohler, S. (2005): Geothermisch angetriebene Dampfprozesse; Analyse und Prozessvergleich binärer Kraftwerke, V + 184 S., Berlin [Dissertation].

Münch, W., Sistenich, H.P., Bücker, C. & Blanke, T. (2005): Möglichkeiten der geothermischen Stromerzeugung im Oberrheingraben. – VGB PowerTech 10/2005: 9 S., Essen.

Sanner, B. (1992): Erdgekoppelte Wärmepumpen: Geschichte, Systeme, Auslegung, Installation. - IZW-Berichte 92-2: 328 S., Eggenstein- Leopoldshafen.